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OPEN GRADED
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OPEN-GRADED BASES
FOR AIRFIELD PAVEMENTS

by

Walter R. Barker

Geotechnical Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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Water has long been recognized as a major contributor to pavement failures. To lessen the potential for damage due to water, the US Army Corps of Engineers established drainage criteria for bases and subbases in airfield pavements. Since the establishment of the drainage criteria, the use of dense-graded aggregate has become the most used material type for airfield pavement bases. Laboratory studies conducted in the late 1960's indicated that the dense-graded bases were almost impermeable and would not meet the drainage criteria.

Bases constructed from a uniform size aggregate (an open-graded base) would provide the required permeability but do not have the stability of a denser graded

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base. A literature review and field survey on the use of open-graded bases and the results of a pilot test section to illustrate the structural capabilities of open-graded bases and follow-up on some ongoing studies are included in this report.

The literature review and field survey gave indication of a number of applications of open-graded bases in both highway and airfield pavements. All indications were that pavements constructed with open-graded bases performed very well. There were indications of construction problems because of the instability of the base in the unconfined state. The results of the pilot test section confirm the literature review and field test section results. Based on the results of the test section, it was recommended that criteria for use of open grades be developed.
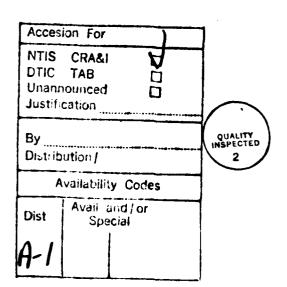
PREFACE

The report presented herein was sponsored by the Office, Chief of Engineers, US Army, under the work effort "Open-Graded Bases for Airfield Pavements" of the Facilities Investigation and Studies (FIS) Program.

The study was conducted by the US Army Engineer Waterways Experiment Station (WES), Geotechnical Laboratory (GL). Dr. W. R. Barker, Pavement Systems Division (PSD), prepared this report under the general supervision of Dr. W. F. Marcuson III, Chief, GL, and Mr. H. H. Ulery, Jr., Chief, PSD, GL. Mr. R. G. Ahlvin, consultant to WES, provided a technical review of the report. He also provided valuable input to the report. The report was edited by Ms. Odell F. Allen, Information Products Division, Information Technology Laboratory.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons per square yard	4.5273	cubic decimetres per square metre
gallons (US liquid)	3.785412	cubic decimetres
inches	2.54	centimetres
kips (force)	4.448222	kilonewtons
miles (US statute)	1.609347	kilometres
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic feet	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
tons (2,000 pounds, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

OPEN-GRADED BASES FOR AIRFIELD PAVEMENTS

PART I: INTRODUCTION

1. There is expanding interest in improving the drainage of pavements. Focus has been on the use of open-graded aggregates for base course of flexible pavements or subbase beneath portland cement concrete (PCC) slabs of rigid pavements. For open-graded aggregates to function as drainage layers, they must have voids sufficient to permit rapid drainage and stability sufficient to prevent displacement or distortion because of construction operations and traffic on the completed pavement. Since these two attributes of base-type aggregate materials are somewhat in opposition to each other, a compromise will be necessary.

Purpose

2. This study was to assemble and examine pertinent results of work by others and to conduct some trial tests of the behavior of promising materials. Further study would be identified and recommended, and, to the extent practicable, a posture for the immediate future would be suggested.

Scope

3. Search of pertinent literature extended to past Corps of Engineers (CE) studies, CE and Federal Highway Administration (FHWA) design guidance for subdrainage, leading texts on drainage, and some available studies which included summaries of past work. Pilot tests of the structural feasibility of using open-graded base in a flexible pavement were performed. Because the literature survey identified quite a number of ongoing studies to be shortly completed, follow-up on these studies was incorporated prior to finalizing the study report.

Literature Review

4. It seems that one of the major causes for airfield pavement failures is quite well known, yet solutions are not known or are not applied in the

design of airfield pavements. The problem is recognized as being water in the substructure of the pavement. Possibly the reason the water problem solution is so elusive is that effects of water can be diverse and that some attempts at solving the water problem have created more or even worse problems than were solved.

5. Rollings conducted a literature review early in 1981 on subsurface drainage for airfield pavements as a study for the Office, Chief of Engineers. This review was reported as a memorandum for record and is contained in this report as Appendix A. (In several places supplementary footnotes have been added to Rollings original memorandum).

6. As pointed out by Rollings, one design measure being advocated for mitigating the damage of water is by the use of open-graded bases. The use of an open gradation for the base material actually performs two functions. First, the open base permits rapid draining of base, and second, if the pavement should be loaded while the base contained water, the open structure of the base would prevent development of excessive pore pressure.

7. The rapid drainage of the bases is particularly important for rigid pavement to prevent pumping at the joints. Cedergren (1974) was a particularly strong advocate of open-graded bases. He was particularly impressed by the performance of pavement sections having a base course of 1/2 to 2 in.* of crushed trap rock. The permeability of this base was such that a 3-in.-diam hole drilled into the base could not be filled by pouring water from a pail. It is interesting to note that this extremely open base was built back in the late 1950's at a time when Arthur Casagrande was active in developing airfield pavement design criteria.

8. As a result of his literature review on subsurface drainage, Rollings recommended visits to airports in Jacksonville, Fla., Kansas City, Kan., and Portland, Ore., and to Transportation Departments in Michigan and California. Accordingly, Rollings visited the Jacksonville airport in June 1981 and a memorandum for record covering his visit is included in Appendix B. COL Irving Kett, then assigned to the Pavement Systems Division, Geotechnical Laboratory at the Waterways Experiment Station (WES), visited the other two airports and the Transportation Departments in Michigan and California.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

COL Kett conducted site surveys at the indicated locations in the United States where open-graded bases were being used for drainage in pavement systems. The memorandum for record for this survey is also contained in Appendix B. The findings of COL Kett in this survey were very informative, especially the information obtained from California Department of Transportation and Michigan Department of Transportation. COL Kett provided important information on the detrimental effects of water in the pavement system, which stresses the complex nature of the interaction of various components of the pavement system.

9. The following quotation from COL Kett's report seems to summarize the literature in regard to water and pavement behavior.

> It is difficult, if not impossible, to separate sub-drainage design from the overall consideration of the pavement structure. The general harmful influence of water upon a pavement structure is considered to be a major contributor to unsatisfactory performance and even failure. This situation manifests itself in rutting, cracking, faulting, increasing roughness, and a relatively rapid decrease in the level of the pavement's serviceability.

10. The concept of the drainage layer as visualized by COL Kett consists of a drainage layer having a permeability of at least 10,000 ft/day, a filter layer or filter cloth, collector trenches or perforated collector pipe, pipe outlets, and outlet markers.

11. From the studies by Cedergren, Rollings, and Kett, it is apparent that water in the pavement is a major contributing factor to pavement failures. What is very distressing is that, even though Casagrande established drainage criteria and Nettles and Calhoun (1967) showed that dense-graded bases being used for airfield pavements did not meet the drainage criteria, dense-graded bases continue to be used. Probably one contributing factor is too broad acceptance of the concept that strength and density are synonymous. As a general rule, for a given gradation of base, the strength does increase with density, but increasing density by adding fines does not necessarily increase the strength. The resilient modulus tests conducted at WES for the New Jersey Department of Transportation (Barker and Gunkel 1979) indicated that an open-graded base, having only 109 pcf density, had a higher resilient modulus than a comparative dense-graded base having a density of 142 pcf. This was true even though the dense-graded base was tested at optimum water content.

6

12. From the above discussion, the literature reviews, and the field surveys by Rollings and Kett, the conclusion reached is that there is a need for a more open-graded base in airfield pavements, but such a base must be capable of being placed and compacted and must provide adequate stability as a pavement element.

13. The literature survey made by Rollings identified a National Highway Research Program synthesis on subsurface drainage under preparation. It also found a number of other pertinent studies by FHWA contract, NCHRP contract, and HPR studies being conducted. Because of these, a follow-up literature examination was conducted after sufficient time had elapsed to permit completion and reporting of the ongoing studies listed by Rollings. The follow-up study is reported in Appendix C and lists other pertinent references found more recently. Much of this appendix material was anticipated by the survey results presented in Appendix A. Other pertinent references available since the earlier survey are also included.

14. Examination of the more recent literature which is summarized in Appendix C reinforces findings that dense graded bases are nearly impermeable, that open grading can provide adequate permeability, that such bases can be constructed with care, that costs of such bases are competitive with dense bases, that stabilities of open bases can be sufficient but problems can easily develop, and that stabilization of open-graded materials improves and generally results in adequate stability.
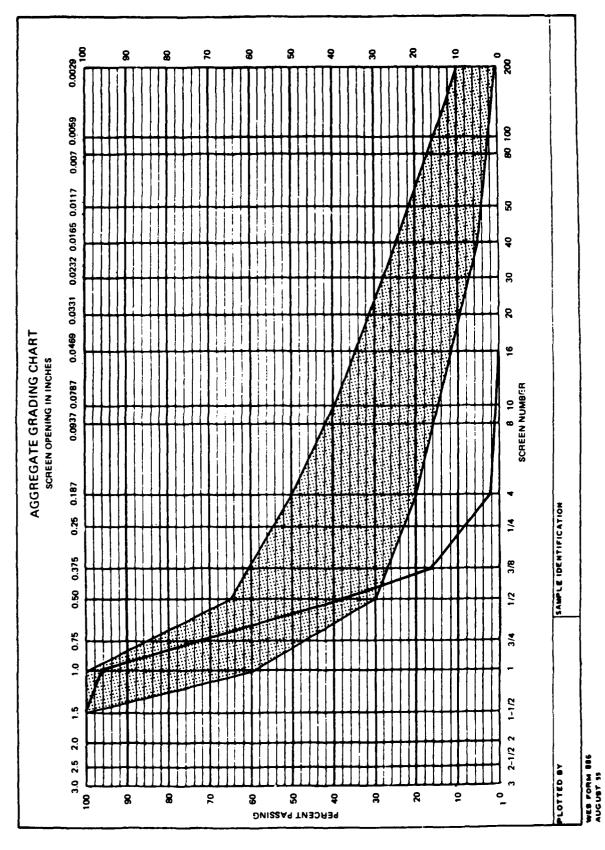
PART II: PILOT TEST SECTION

Purpose

15. Based on the conclusion that a more open-graded base was needed, a prototype pavement section was built and trafficked in 1982. The section was planned as a pilot section to be constructed at minimum cost to illustrate the structural feasibility for using an open-graded base in an airfield pavement.

Test Section

16. The pilot test section planned was to be 15 ft wide and 70 ft long having a sandy silt subgrade, a 6-in.-cement stabilized clay gravel subbase, a 6-in.-open-graded base, and a 3-in. asphalt concrete (AC) surface. The section was subdivided into three base test items above the prepared subbase. The first item (Item 1) was a section 15 ft wide and 15 ft long having an open-graded base of crushed limestone meeting the American Society for Testing and Materials (ASTM) Specifications D448 and D693 for a No. 57 stone. The ASTM standard specifies "reasonably clean, tough, durable fragments" requiring not less than 75 percent by weight of particles having at least two fractured faces, and limits "flat or elongated particles" to no more than 15 percent by weight. The gradation curve for the stone is given in Figure 1. For comparison, the CE guide specification (CE-807.07) for (dense) "Graded-Crushed-Aggregate Base Course" has the limits for 1-1/2-in. maximum aggregate shown in Figure 1. The second item (Item 2) was also 15 ft wide and 15 ft long and had a base of the same stone. The difference between the two items was that Item 2 contained a geoweb fabric located at midheight of the base. The geoweb used was tensor SS-2 geoweb having a web dimension of approximately 1.1 by 1.5 in. Between Items 2 and 3 was a 10-ft-long section to allow for transition of the base of Item 2 to the base of Item 3. Item 3 was 15 ft wide and 30 ft long. The base of Item 3 was the same No. 57 stone only stabilized with 2 percent asphalt.

17. The construction details of the test section are given in typical longitudinal section in Figure 2.

Figure 1. Gradation curve for No. 57 crushed limestone and equivalent limits limits for Corps of Engineers dense-graded aggregate
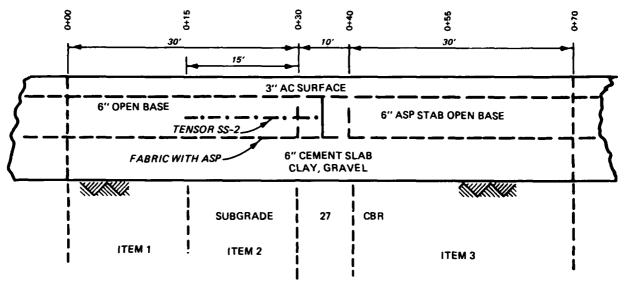
9

Figure 2. Typical longitudinal section

Selection of a Free-Draining Base

18. The problem was to select a base material that would be free drain-
ing and yet be stable during construction and under traffic. For drainage
criteria, the goal was to select a base that would have a permeability of
10,000 ft/day or greater. Such a permeability would provide very rapid drain-
age and would prevent buildup of pore pressures. Three gradations of crushed
stone chosen for initial study are shown in Figure 3. These gradations are
similar to the gradations of free-draining bases reported in the literature.
Since one section of the test was to have a stabilized base, the final selec-
tion for the free-draining material was to be based on the behavior of stabi-
lized sample of the trial gradations. For each of the gradations, samples
were stabilized using both cement and asphalt.

19. For the cement stabilization, tests were conducted to determine the
amount of cement paste required to coat the aggregate. By using different
amounts of cement paste in the mix and observing the coating of aggregate, it
was determined that 10 percent by weight of cement was required to coat the
aggregate. Three samples 6 in. diam by 12 in. high were made for each of the
three gradation stones. The samples were cured for 7 days and tested in
compression. The difference in compressive strength between the three grada-
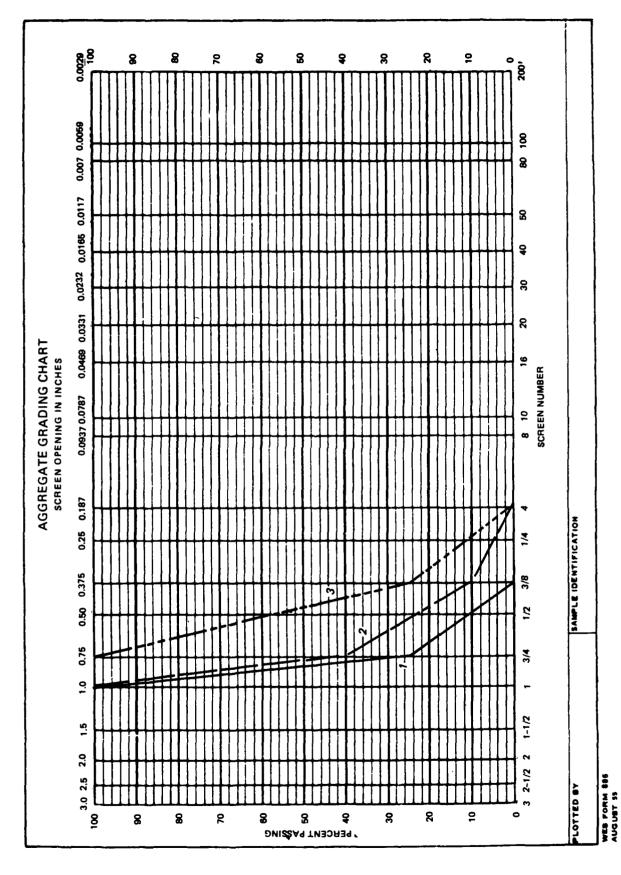tions was insignificant. The average strength for all samples tested was
550 psi.

Figure 3. Gradations for open stabilized base

11

20. Selected test samples are shown in Photos 1, 2 and 3. The strength of the stabilized materials was not as high as expected, which created doubt in the value of using cement-stabilized base in test sections.

21. Asphalt-stabilized samples were also prepared for each of the gradations. In the asphalt stabilization, asphalt contents of 1.5 and 2 percent were used to prepare samples, and the asphalt coating of the aggregate was judged by observation. An example of the use of 1.5 percent asphalt is shown in Photo 4. As can be seen in the photo, the aggregates are not fully coated. In contrast, the 2 percent asphalt provided nearly complete coating for all of the aggregate. Although the laboratory tests were started with the intent of looking at only three gradations, a fourth gradation was introduced. This gradation was the ASTM No. 57 stone (where gradation is shown in Figure 1) which was introduced because it was similar to the No. 2 gradation and was commercially available. Photo 5 shows the sample of Mix 4 at 2 percent asphalt. This particular gradation and asphalt content seem to produce the most desirable mix. The behavior of the mix was observed during compaction and was judged satisfactory. When the gradation of all of the mixes is compared with the data provided in Figure A1, it is seen that a base constructed from either of the mixes should provide a permeability in excess of 10,000 ft/day. The permeability of the asphalt coated aggregate samples was demonstrated by the use of a falling head permeability device. The device consisted of a column of water 12 in. high and 2 in. diam. When the column was released, the water flow through the sample was so rapid that the time for emptying the water contained therein could not be measured. Because of the poor performance of the cement-stabilized samples and good behavior of the asphalt-stabilized samples in the laboratory, asphalt stabilization was chosen for the material to be used for the stabilized item of the test section.

12

PART III: CONSTRUCTION OF THE TEST SECTION

Location

22. The test section was located in an opened-ended covered hangar (Hangar 4) at WES. The site at the northwest corner of Hangar 4 was over part of an old test section that had been used in connection with an MX road study conducted the previous year. This site was chosen because the hangar provided somewhat controlled moisture conditions and because a subgrade consisting of a sandy silt was partly in place.

Subgrade

23. To ensure uniform subgrade conditions, the site was excavated to a depth of 45 in. The excavation was filled to within 15 in. of the surface with the sandy silt subgrade material. The subgrade was compacted and rolled with a steel wheel roller. The California Bearing Ratio (CBR) was measured as 27 percent with a water content of 8.3 percent.

Subbase

24. A cement-stabilized sandy gravel was chosen for the subbase to provide a stiff working platform for the placing of the base and as protection for the subgrade during the load test. The subbase material was prepared by spreading the sandy gravel on a surfaced area and applying 8 percent by weight of PCC evenly over the surface of the sandy gravel. The cement was then mixed into the sandy gravel with a pulvimixer and front-end loader. Moisture content of the sandy gravel was 7.3 percent at the time of mixing.

25. The gravel-cement mixture was moved to the test section in dump trucks and placed in a single 7-in. lift (Photo 6). This lift was compacted using a 50-ton self-propelled roller at a tire pressure of 60 psi (Photo 7). A final rolling of the subbase was provided with a steel-wheel roller (Photo 8). The surface of the subbase was sealed using asphalt and a nonwoven filter fabric. The surface was first sprayed with an AC-5 asphalt at about 0.3 gal/sq yd, and a layer of nonwoven filter fabric was placed over the AC-5 coated surface (Photo 9). The fabric was then sprayed with another coat of

13

AC-5 asphalt at about 1.5 gal/sq yd, and the surface was allowed to cure for about 2 weeks. The completed subbase is shown in Photo 10.

Base Course

26. The unstabilized crushed limestone of Items 1 and 2 was placed in two 3 in. lifts using the same spreader as was used for the subbase (Photo 11). Each lift was compacted using a steel-wheel vibratory roller. Compaction was accomplished in one pass of the 12,500-lb drum without vibration followed by two passes using 2,400 vibrations per minute, nominally applying a force of 18,000 lb. After placing and compacting the first lift, a layer of tensor SS-2 geogrid was placed in Item 2, the second one-half of the test section. The second lift was then placed and compacted using the roller and compaction pattern. The material, even after compaction, was loose and unstable to most traffic. The coarse texture of the surface is shown in Photo 12. The base did prove sufficiently stable for later paving operations, but this would not have been true if the paving operation had involved much stopping, starting, or turning.

27. The asphalt-stabilized base was also placed in two lifts, each being 3 in. thick. For this base the asphalt was mixed at a local asphalt plant using aggregate furnished by the Government. The asphalt-stabilized base material was delivered to WES in an open dump truck and spread using the same spreader as was used for the subbase and base. The temperature was not critical, but the mix appeared to have been prepared at a normal 230 to 250° F and by the time of delivery was reduced to an estimated 180 to 200° F.

28. The asphalt-stabilized base was compacted in the same manner as the unstabilized base. The finished surface of asphalt stabilized base is shown in Photo 13. Although difficult to see in the photograph, there was sufficient asphalt for complete coating of the aggregate. The stability of this base was much higher than the unstabilized base of Items 1 and 2.

Surface

29. The section was surfaced using 3 in. of asphalt surface mix purchased from a local supplier. The surface was placed in two lifts, each lift being 1-1/2 in. thick. At the time of arrival the temperature of the asphalt

14

cement was approximately 300° F. Vibratory rolling was first attempted with the temperature still at 200° F but was discontinued due to the instability of the surface. The surface was allowed to cool to 160° F and rolled with a vibratory roller. Considerable movement in the base of both items could be noted. The movement of the base of Items 1 and 2 was greater than the movement of the base of Item 3. The second lift was placed (Photo 14) and rolled (Photo 15) in a manner similar to the first lift. In the final rolling of the surface, the instability of the base of all items could be noted. The completed test section is shown in Photo 16.

30. These indications of base movement or instability under rolling, while visually evident as "weaving" of the surface and some cracking of the bending surface as it emerged from beneath the roller, did not result in significant irregularity of the surface either longitudinally or in cross section. Finish rolling with eight coverages using a seven tire, 50-kip gross weight roller, 60-psi inflation pressure, generally sealed the cracks, and a final pass of the steel drum roller with no vibration resulted in a satisfactorily smooth and level test section as shown in Photo 16.

PART IV: TRAFFIC

31. The traffic placed on the test section was to simulate traffic from an F-4 aircraft. The loading was applied by a single tire loaded to 27,000 lb and inflated to 265 psi tire pressure. The pavement to receive traffic was 60 in. wide and was divided into six tire lanes. The traffic lane layout can be seen in Photo 16. To apply traffic the loaded tire was towed along a tire lane forward and backward. Then the tire was shifted over by one lane. A trip of the loaded tire along a tire lane constituted a coverage for that tire lane. Thus, a round trip of the load cart applied two traffic coverages for a particular tire lane. To avoid having a jump from 0 traffic to 100 percent traffic at the edge of the traffic lane, the outside tire lanes were skipped every five cycles of loading. This resulted in two outside tire lanes having only 80 percent as much traffic as the center four tire lanes.

32. At intervals during traffic the application of traffic was stopped, and data on the performance of the test sections were obtained. Photographs were taken and cross-section data were obtained at traffic coverage levels of 0, 10, 30, 100, 300, and 1,000. Falling weight deflectometer (FWD) data were collected at 0, 100, 300, and 1,000 coverages using a nominal 15 kip-loading.

33. An overall view of the test section prior to traffic is shown in Photo 16. Traffic was started on 7 June and after stopping at 10 and 30 coverages for cross-section data, 60 coverages of traffic were applied during the day. Traffic was resumed on 8 June applying an additional 40 coverages before stopping for cross-section and FWD data. Views of each test item at 100 coverages are shown in Photos 17, 18, and 19. As can be seen in the photos, rutting of Item 1 is the greatest with little rutting of Item 3. Due to equipment problems, traffic was not resumed until 20 June. A total traffic level of 300 coverages was obtained by the end of the day on 20 June. On 21 June photos were taken, cross sections were obtained, and FWD tests were conducted. Views of the test items at 300 coverages are given in Photos 20, 21, and 22. It can be noted that no cracking of the surface is apparent although rutting particularly in Item 1 is quite severe. Traffic was resumed on 22 June and continued through 29 June when traffic was stopped at 1,000 coverages. All data were obtained at that traffic level, and traffic was terminated because of excessive rutting of the test section.

16

Cross-Section Data

34. Cross-section data were taken at sta 0+10, 0+15, 0+25, 0+30, 0+47.5, 0+55, and 0+62.5 using a rod and level. These cross sections gave two cross sections for Items 1 and 2 and three cross sections for Item 3. The cross-section data relative to the beginning surface are shown in Figures 4 through 10.
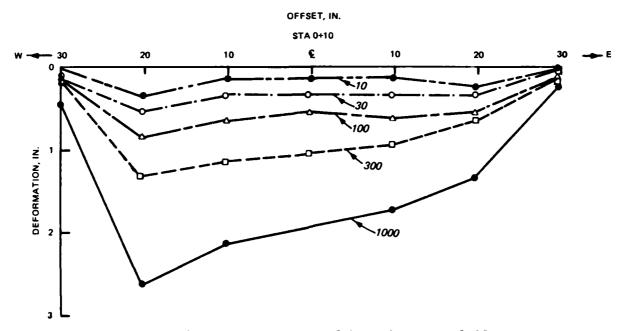
OFFSET, IN.

STA 0+10

Figure 4. Cross section of Item 1 at sta 0+10

FWD Test

35. The FWD used was a model 8000 manufactured by Dynatest which produces an impulse load to the pavement by dropping a 440-lb load from a height that can be varied from 0 to 15.7 in. The load is transmitted to the pavement through an 11.8-in.-diam plate. The pavement deflections were measured by the use of velocity transducers placed on the pavement surface at distances of 0, 12, 24, 36, and 48 in. from the center of the plate. The deflection at the center of the plate was measured through a hole in the plate and thus the measured deflection is the actual deflection of the surface. The plotted deflection basins for the FWD test prior to start of traffic are shown in Figure 11, and the basins for subsequent test are shown in Figure 12. Both figures show comparative strengths between the stabilized (Item 3) base and unstabilized

17
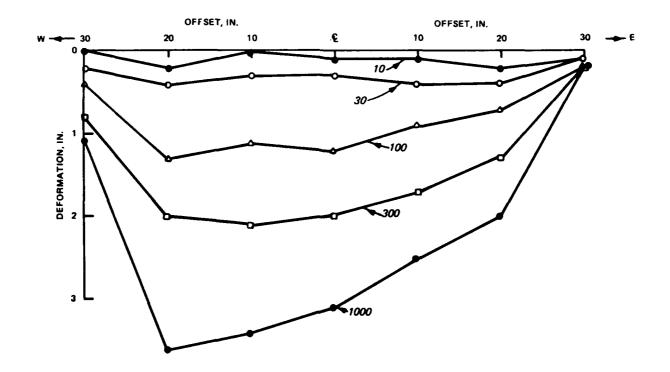
Figure 5. Cross section of Item 1 at sta 0+15
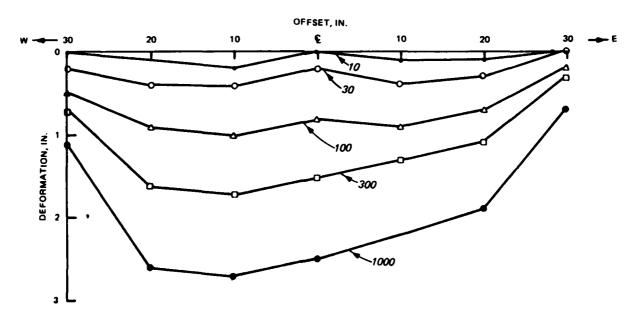
Figure 6. Cross section of Item 2 at sta 0+25

18
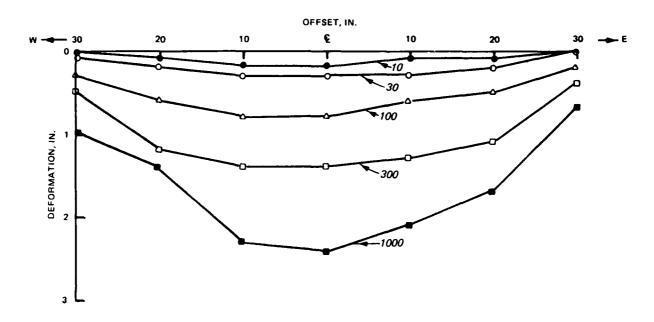
Figure 7. Cross section of Item 2 at sta 0+30
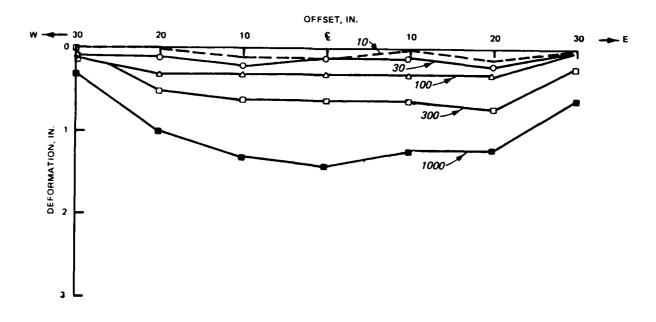
Figure 8. Cross section ot Item 3 at sta 0+47.5

19
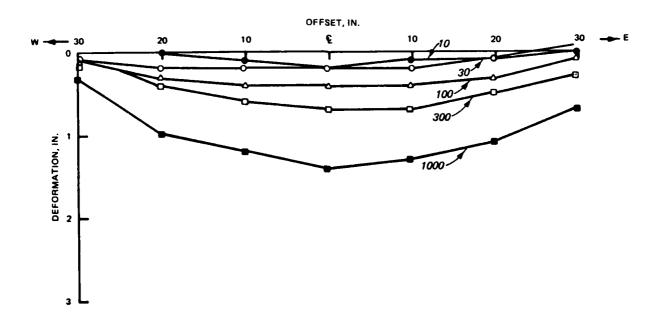
Figure 9. Cross section of Item 3 at sta 0+55
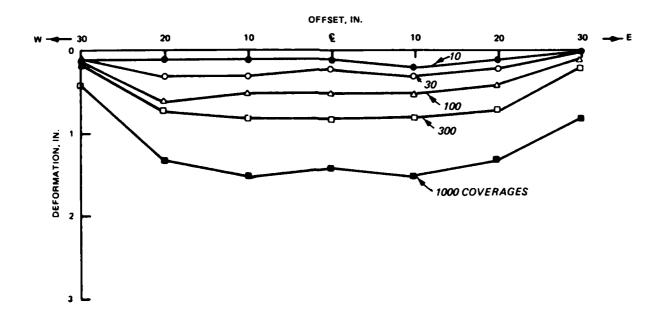
Figure 10. Cross section of Item 3 at sta 0+62.5

20

Figure 11. FWD deflection basin at "0" coverage

(Items 1 and 2) base consistent with the effects of base movement observed
during rolling of the asphalt surface. The comparisons are also consistent
with eventual depression magnitudes under traffic as shown in Figures 4 and 10
and discussed in the following section.

Figure 12. Deflected surface for FWD tests at coverage
levels of 100, 300, and 1,000

PART V: ANALYSIS OF TRAFFIC TEST DATA

36. The F-4 loading with the 27,000 lb at a 265-psi internal tire pressure is considered to be a severe loading for an Army airfield pavement. For the upper layers of the pavement such as the surface and base course, this loading, because of the high tire pressure, is almost as severe as heavier bomber aircraft. Because of the instability of the base material under only 3 in. of surfacing, as indicated by the movement occurring during construction, there was a con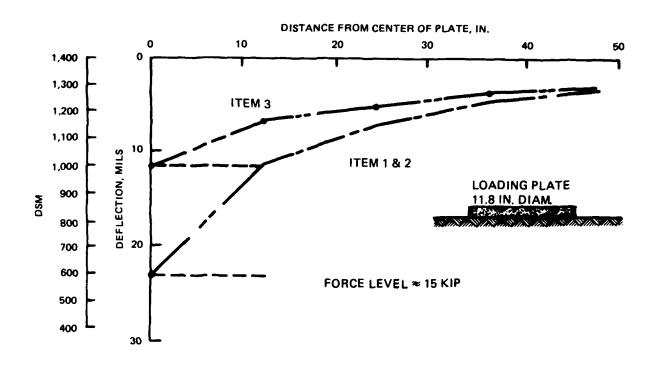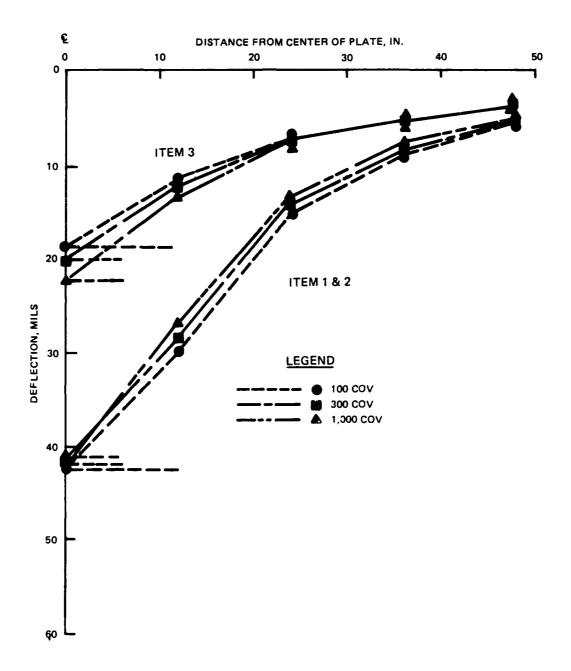cern that complete failure of the test section would occur during the first pass of the load cart. Therefore, it was surprising that the first of the traffic was uneventful. The movement under the load was more noticeable for Items 1 and 2 than Item 3. As traffic progressed, it became evident that more permanent deformation was occurring in Items 1 and 2 than was occurring in Item 3. Figure 13 presents a plot of the development with traffic of permanent deformation for each of the test items. As can be seen by 100 coverages, the deformation of Items 1 and 2 was approximately twice that of Item 3. At 100 coverages the deformation of Item 1 was about the same but slightly larger than the deformation of Item 2. After 100 coverages, the deformation in Item 1 increased at a greater rate than the deformation in Item 2. At the end of traffic (1,000 coverages) the deformation of Item 2 was 79 percent of the deformation of Item 1, and Item 3 was 44 percent that of Item 1.

37. During the early part of traffic, it was noted that for Items 1 and 2, the deformed surface formed a "W." This W shape can be noted in the cross sections given in Figures 5 and 6. The development of the W is an indication that some shear movement is taking place in the upper layers. Later in traffic the deformation basin formed a deep bowel-type basin without upheaval at the edge which would be an indication that the deformation is a result of deep consolidation. Figure 14 presents a schematic representation of traffic effects.

38. Fatigue cracking of the surface did not appear during traffic. At about 10 coverages a single crack did appear along the west edge of the traffic lane of Items 1 and 2. Later in traffic a crack appeared along the east edge of the traffic lane. Both cracks grew in width as the deformation increased. The fact that there was no fatigue cracking of the surface was an indication that very little movement was occurring in the base. The
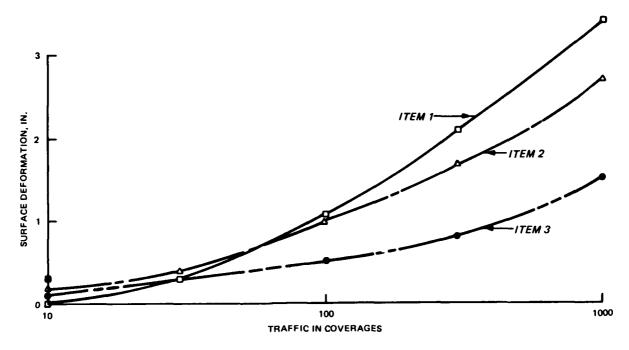
23

Figure 13. Maximum surface deformation as a function of traffic

longitudinal cracks along the edge could be attributed to the deep deformation
creating the sharp bending of the surface at the edge of the traffic lane.

39. The FWD test conducted before and during traffic revealed interest-
ing information concerning the behavior of the test section. It is seen by
comparing the deflection basin before traffic to the deflection basin at
100 coverages that the maximum deflections from the FWD doubled with the start
of traffic. As traffic increased after 100 coverages, the deformations mea-
sured in the FWD tests (Figure 12) decreased for Items 1 and 2, but increased
for Item 3. One possible explanation for results obtained in the FWD test
would be in the performance of the PCC stabilized layer under the base. This
layer prior to traffic would have been intact. During traffic the cement-
stabilized layer cracked, the cracking being more rapid in Items 1 and 2 than
in Item 3. Prior to 100 coverages of traffic, the cracking for Items 1 and 2
was complete and then the section began to stiffen because of consolidation of
the lower layer. For Item 3 the stiffer base prevented the rapid breakup of
the cement-stabilized layer. The continued increase in the FWD deflection of
Item 3 could indicate a breakup of the asphalt-stabilized base.

40. Traffic was stopped at 1,000 coverages because the deformations had
become so great. The surface of all items at this time appeared to be in good
condition with no fatigue cracking.

SHEAR DISPLACEMENT
BENEATH TIRE

SECTION AS
CONSTRUCTED

TIRE
LOAD

PAVEMENT

BASE

SUBBASE

SUBGRADE

DISTRIBUTED TRAFFIC

TIRE
PASS

TIRE
PASS

TIRE
PASS

ADJACENT PASSES   EDGE PASSES

INDUCE COMPENSATING INDUCE CUMULATIVE

SHEAR REVERSALS   SHEAR MOVEMENTS

THE PROCESS PRODUCES THE "W" PATTERN

COVERAGES OF WHEEL-PASS REPETITIONS

DENSIFICATION OR DEEP SHEAR DISPLACEMENT

Figure 14.   Schematic representation of traffic effects

25

41. After stopping traffic, a 3-in.-diam hole was drilled through the AC surface to the base material. To check the permeability of the base, water was poured into the hole from a 5-gal pail. The 5-gal pail could be emptied in about 1 min without overflowing from the hole. The unstabilized base was only slightly more permeable than the stabilized material.

42. Observation trenches were also cut through the surface and base to the stabilized subbase. For all items the top of the subbase had the same shape as the surface pavement indicating that most of the deformation did indeed occur deeper in the section. Also, the thickness of the base material was still approximately 6 in. indicating little deformation in the base material.

43. Since this was a pilot test study and not one justifying extensive effort, the silty sand subgrade placed uniformly and compacted nominally with the steel drum roller was considered to be a more than adequate platform for the study, particularly considering the use of the cement-stabilized sandy gravel subbase. The 27 CBR found for the subgrade easily justified this expectation for pavement to support an F-4 aircraft loading, but this was the "as-placed" CBR for the 8.3 percent moisture content and 121.1 psf density determined for the subgrade. No substantial adjustment or curing of the moisture was expected, as is known to apply to in-service pavements following construction. Therefore, no effort was invested in subgrade soil strength assessment. It now appears that because subgrade preparation was in early August of 1982 and traffic applied to the test section in July of 1983, substantial soil moisture and strength adjustment may have occurred. This and the unanticipated cracking of the cement stabilized subbase have apparently resulted in a far less substantial structure than intended.

44. This combination of circumstances, which have led to the total structure strength being challenged within the 1,000 coverages applied rather than only base stability being a factor, may have a fortuitous aspect. The after-traffic trenching indicated no thinning of the base layer and thus no internal shearing within the base. However, the deformation of the total section was different for the three different base sections. Item 3 with bituminous stabilization had the least deformation. Item 2 with the geogrid reinforcement had somewhat less deformation than did Item 1 with no geogrid and no stabilization. This implies that the different base types each had a different capability for distributing stresses from top to bottom of the layer. Or,

26

in another sense, for equal behavior within the structure the stabilized base thickness would be less than for the base with geogrid and either would be thinner than the nonstabilized base.

45. This finding indicates that for development of open-graded bases for drainage, in addition to permeability rates and stability to support construction and perform as a base layer, it may be necessary to also learn to treat varied load or stress distributing characteristics.

46. In the unstabilized base material it appeared that the top 3 in. of the base had sustained more degradation than the bottom 3 in. To see if this was in fact true, sieve analysis was conducted on samples from the top half and from the bottom half of the base. The gradations obtained are shown in Figure 15. From the gradation curve it would appear that there is no significant difference in the two samples. Still, from observation it did appear that the bottom half of the base was unchanged. This could indicate that an additional 3 in. of cover over the open-graded base may be required.

47. The tensor fabric of Item 2 was uncovered and appeared to be in good condition. There were no tears or splits in the fabric, and the fabric was still located at midheight of the base.

48. In spots the top of the asphalt stabilized open-graded base of Item 3 was loose granular material. The maximum depth to which the debonding of the aggregate extended was only about 2 in. Again, the indication is that 3 in. of AC cover is not sufficient to protect an open-graded base under this loading. The debonding of the asphalt base could also help explain the increase, with traffic, of the deflection in the FWD test.
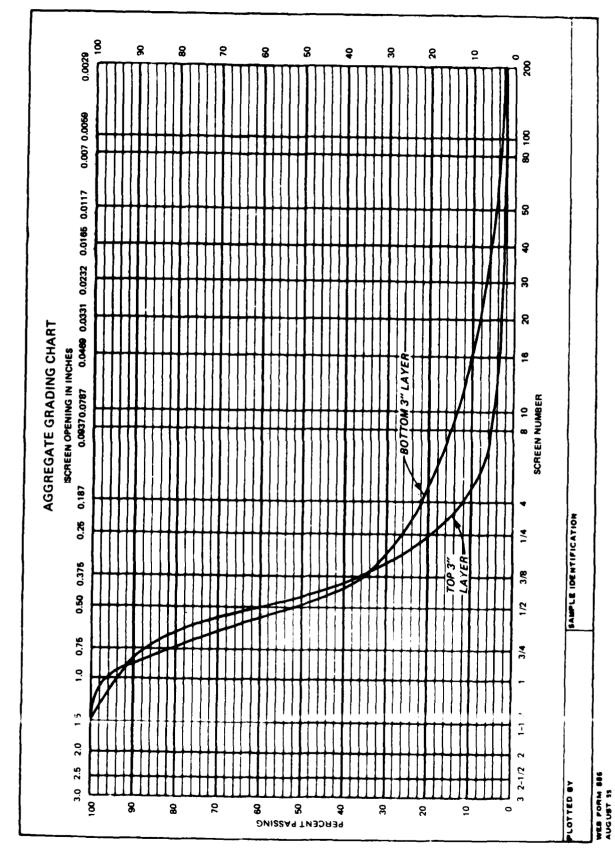
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Figure 15. Gradations for top and bottom of open-graded base

28

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

49. Based on the results of the pilot test section, the literature review, and the examination of field installations, the following conclusions are presented.

　a. For the majority of the airfield pavements constructed with dense-graded bases, the base course is nearly impermeable.

　b. Airfield pavements constructed with open-graded bases have been successfully constructed and have performed well in field installations. The open-graded bases can provide adequate permeability.

　c. Certain types of open-graded materials such as were used in this pilot test section would give stability problems in support of rolling thin cover layers.

　d. Asphalt stabilization of an open-graded base will increase the stability of the base and will improve the pavement performance.

　e. The stiffness of a pavement system with an open-graded base, as measured by the FWD, is comparable to the stiffness of pavement system having conventional bases.

　f. The F-4 aircraft loading did not cause thinning of any of the open-graded test items, which indicates there was no significant shear distortion within the bases tested.

　g. There is an implied need to develop an understanding of the relative load distributing capability of diverse types of open-graded bases in addition to their drainability and stability.

Recommendations

50. Based on the study, the following recommendations were formulated:

　a. Additional research needs to be conducted on open-graded bases, particularly in regard to methods for increasing the stability of the base in the unconfined state. Such a study could be conducted in the laboratory using small-scale sections. Macadam-type base is one construction procedure that needs to be investigated. Also, continued studies should be conducted with the asphalt and cement-stabilized base.

　b. A field study to determine the consequence of the use of impermeable bases in airfield pavements should be conducted.

　c. Early field demonstration projects for open-graded bases should be planned. Such projects would use an open-graded base shown by the laboratory studies to be more stable than the unstabilized crushed stone used for the pilot test section.

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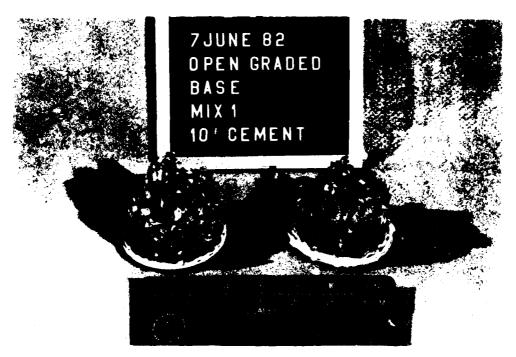
Photo 1. Broken sample of cement-stabilized aggregate (Mix 1)
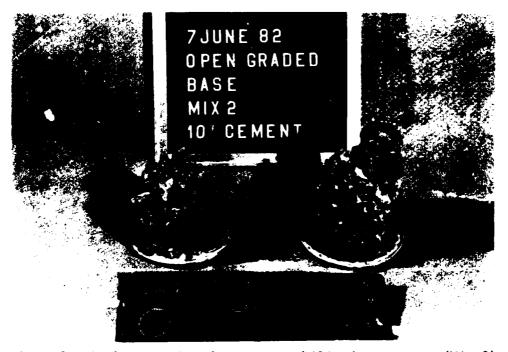
Photo 2. Broken sample of cement-stabilized aggregate (Mix 2)

**7 JUNE 82
OPEN GRADED
BASE
MIX 3
10% CEMENT**
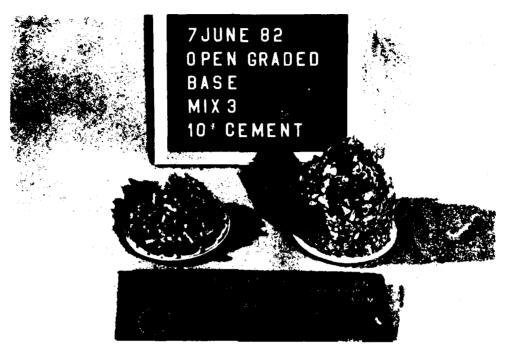
Photo 3.   Broken sample of cement-stabilized aggregate (Mix 3)

**7 JUNE 82
OPEN GRADED
BASE
MIX 3
1.5% AC**
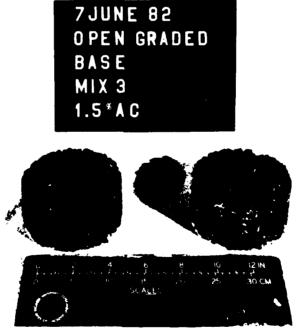
Photo 4.   Laboratory sample of asphalt-stabilized aggregate
(1.5% AC, Mix 3)

7 JUNE 82
OPEN GRADED
BASE
MIX 4
2.0 % AC
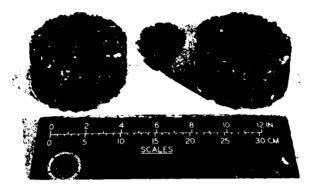
Photo 5. Laboratory sample of asphalt-stabilized aggregate
(2% AC, Mix 4)
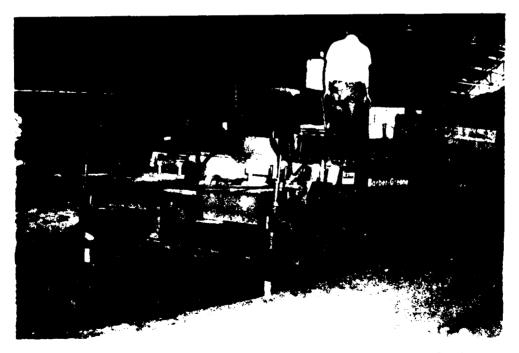
Photo 6. Paver for placing open-graded base and surfacing
for test section
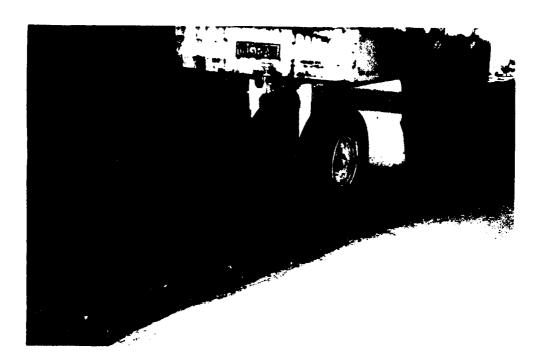
Photo 7.   Roller for compacting test section

Photo 8.   Vibratory roller used in compacting test section

Photo 9. Placing of geotextile fiber below base

Photo 10. Test section ready for placing of base
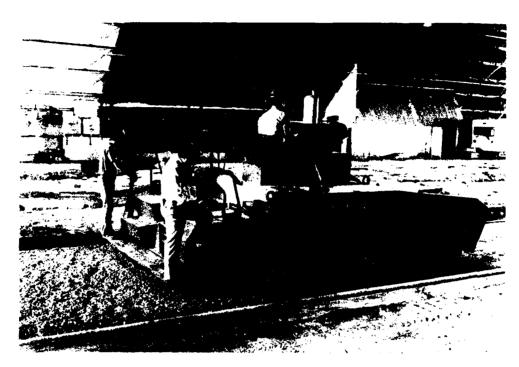
Photo 11.   Placing open-graded base
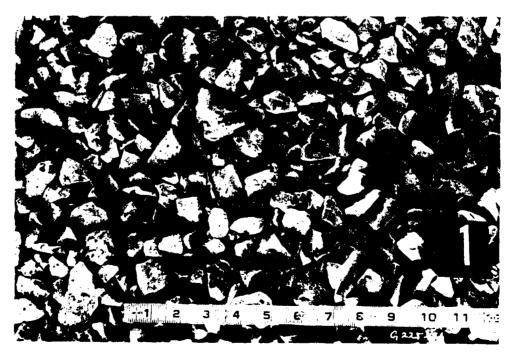
Photo 12.   Close-up of unstabilized open-graded base
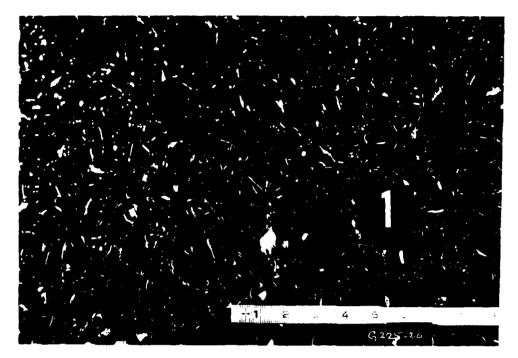
Photo 13.   Close-up of AC stabilized open-graded base

Photo 14.   Placing of AC surfacing
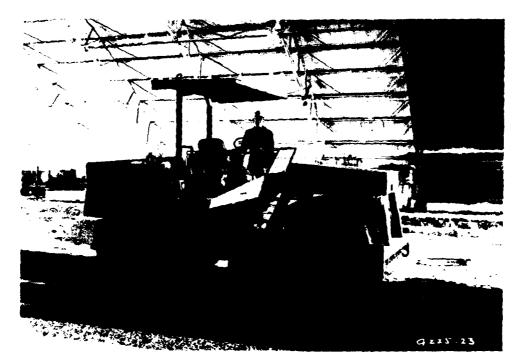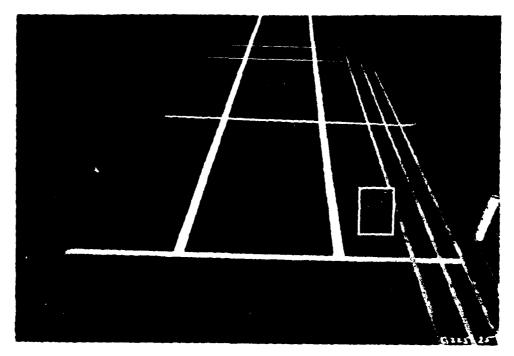
Photo 15.   Compaction of surface layer

Photo 16.   Completed test section
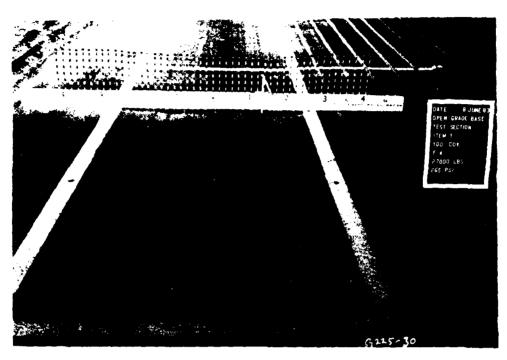
Photo 17.   Rutting of Item 1 after 100 coverages
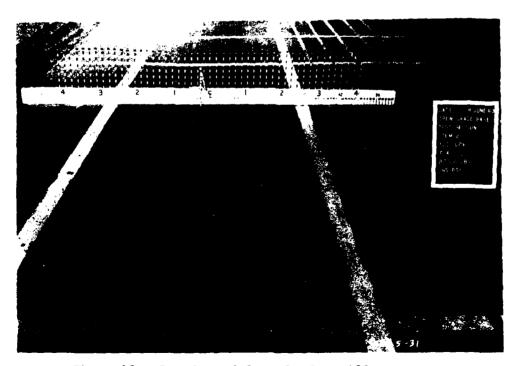
Photo 18.   Rutting of Item 2 after 100 coverages
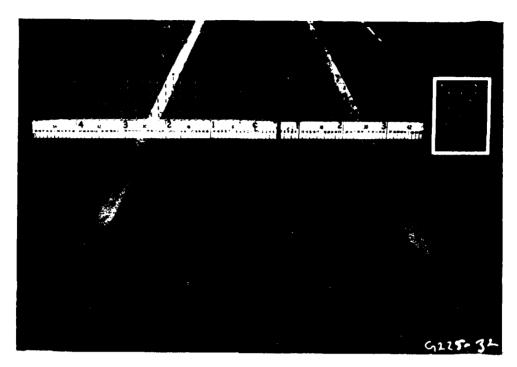
Photo 19. Rutting of Item 3 after 100 coverages
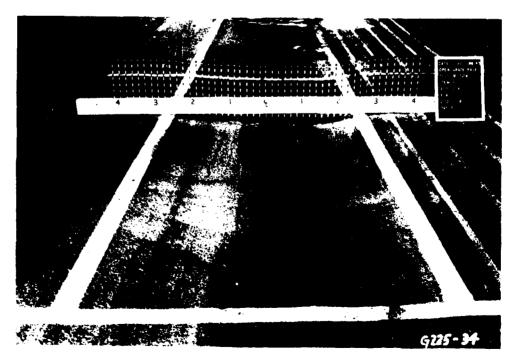
Photo 20. Rutting of Item 1 after 300 coverages
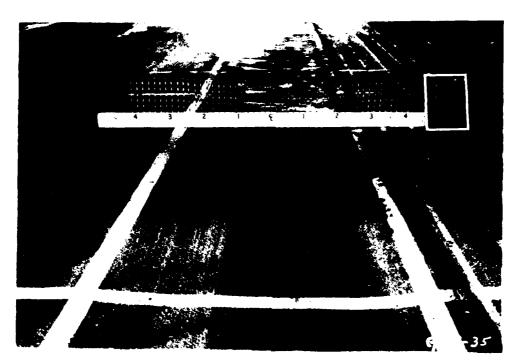
Photo 21.   Rutting of Item 2 after 300 coverages

Photo 22.   Rutting of Item 3 after 300 coverages

APPENDIX A: SUBSURFACE DRAINAGE FOR AIRFIELD PAVEMENTS

Introduction

1. Subsurface drainage of pavements is a topic of considerable interest at the present time. Cedergren (1974)* and the Federal Highway Administration (FHWA) (1980a) have summarized most of the past work and present methods of planning and designing subsurface pavement drainage. A National Cooperative Highway Research Program (NCHRP) Synthesis on subsurface drainage is now being prepared by Professor Ridgeway at the University of Connecticut. The FHWA has sponsored much of the recent pavement drainage work, and a summary of its current projects is listed on page A9.

2. The Corps of Engineers criteria were originally developed by Casagrande and Shannon (1952) and are presented in TM 5-820-2 (Headquarters, Department of the Army 1965). However, laboratory tests by Nettles and Calhoun (1967) found that current Corps of Engineers base course material cannot meet these drainage criteria when compacted to densities required in military airfields. The Corps of Engineers as a minimum must revise base and subbase material specifications to meet existing drainage requirements but should also take advantage of the recent interest and research to review and improve pavement drainage criteria.

Potential Benefits

3. Field studies by a large variety of investigators (summarized by Dempsey 1976) found that in many cases soil layers in pavements become saturated or nearly so even in arid regions. Since the actual final moisture condition under a pavement cannot be predicted during design, saturated California Bearing Ratio (CBR) and modulus of subgrade reaction (k) values corrected for saturation (from consolidometer tests) are used for design. The full potential strength of a soil cannot be used because of our inability to control moisture. This results in dramatically lower design strengths for

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* All references cited in the appendix can be found in the "References" at the end of the main text. Other references applicable but not cited in the text are listed at the end of this memorandum.

many subgrade soils and to a lesser extent also for subbases and bases. The end result is a thicker and more expensive pavement than would be necessary if drainage could prevent loss of soil strength through moisture increases.

4. Pore pressure develops in pavement layers under the action of repeated loads. Although this phenomenon cannot be accounted for in current pavement design methods, it has serious implications for the acceptable performance of the pavement. The effective stress concept of soil mechanics clearly shows that a rise in pore pressure directly reduces the strength of all soils.

5. Professor Dempsey at the University of Illinois has recently developed a gage capable of measuring dynamic pore pressure. This instrument has been used successfully in laboratory tests and at the Illinois test track. Professor Dempsey's experiments (unpublished)* show that a transient load will develop a measurable pulse of pore pressure in the saturated granular materials now used in pavement bases and subbases. Under repeated loading the static or unloaded pore pressure in the layer increases steadily.

6. Pumping of rigid pavements cannot occur without water. If the water can be kept out or removed from the layer below the concrete surface, pumping cannot develop.

7. Water directly attacks the integrity of pavement surfacing materials. It can cause stripping and accelerated weathering of bituminous pavements. In concrete pavements water combined with freezing temperatures can lead to freezing and thawing damage to the concrete.

8. Freezing temperatures and water also lead to potential problems with frost heave in the winter and extreme weakening of the pavement soil layers during the spring thaw. Appropriate drainage facilities can be used to intercept and remove water to prevent formation of ice lenses and the resulting frost heave. Drainage also has the potential of removing water from a perched water table in the pavement structure when the underlying soils are still frozen during the spring thaw.

9. Either positive steps must be taken to control water in the pavement structure or the destructive action of water must be designed for with the resulting increase in pavement costs. Of the potential problems discussed in

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* Subsequent literature review still has not revealed a presentation of research experience with the dynamic pore pressure gage through 1986.

this section, only the reduced design strength from saturated CBR and k values is directly accounted for in pavement design. The other effects are minimized by material specification (aggregate quality to resist freeze-thaw damage in concrete, pumping resistant bases under concrete, etc.) or their effect is ignored because of lack of information (pore pressure). Drainage offers very definite potential advantages which should be studied; however, it should not be considered a panacea for pavement problems.

Drainage Design and Construction

10. Drainage can be used to help solve or mitigate one or more of the problems discussed above, but the drainage system must be designed to accomplish a specific purpose. A single drainage blanket alone, for example, will not solve all the problems mentioned above. There are also different sources of water in the pavement such as surface infiltration, water table, artesian water, capillary water, temperature induced water movements, and several other relatively minor sources. Every drainage system must be specifically designed for each individual site to reflect the problem to be solved, sources of water, local geometry, climate, and similar controlling factors. Cedergren (1974) and the FHWA (1980a) present a variety of different potential design schemes for varying problems and conditions.

11. The design of the drainage systems must ensure that water is removed from the drainage layer, joint drain, etc., collected in a longitudinal drain system, and then removed through outlets.*

12. The first requirement considered in design of a drainage layer is the quantity of water inflow which must be handled. Several approximate methods of estimating this are presented by the FHWA (1980a), but these are recognized as only crude approximations. Better methods and more data in this area are required.

13. The required thickness and permeability of a drainage layer are generally developed from Darcy's law for laminar flow through porous media. This is recognized as only valid for fine grained soils. Flow in open-graded drainage material will be nonlaminar even at relatively low hydraulic gradients; nevertheless, Darcy's law continues to be used since other appropriate

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* Future clogging or blockage of any part of the system must be considered.

A3

techniques have not been developed. Adjustments in the methods of running laboratory permeability tests can help account for nonlaminar or turbulent flow (FHWA 1980a).

14. Casagrande and Shannon (1952) compared the results of four full scale drainage tests of 10 by 75 ft saturated bases consisting of pea gravel and sandy gravel with theoretical calculations. These bases were 6 and 18 in. thick and placed at slopes of approximately 1.5 percent. One item was unsatisfactory due to excessive leakage, but two (pea gravel) out of three of the remaining sections gave reasonable agreement with the theoretical calculations. This is the basis of the Corps subsurface drainage design method. Permeabilities were in the range of 310 ft/day (0.11 cm/sec) to 59,500 ft/day (21 cm/sec) with the sandy gravel averaging 765 ft/day (0.27 cm/sec) and the pea gravel 41,100 ft/day (19.5 cm/sec).

15. Little has been published on the structural requirements of drainage layers. Cedergren (1974) provides several case histories of performance and cross sections of pavements with drainage layers but does not elaborate on how the thickness of the surfaces was developed. Barker and Gunkel (1979) seem to be the first to develop tests for structural requirements for open-graded drainage material. They concluded in part:

> When provided with adequate overburden for confinement, both the stabilized and nonstabilized open-graded aggregates will perform as highway bases. For normal highway loading, the minimum overburden would be approximately 6 in.

Open-graded material has been used successfully unstabilized and stabilized with asphalt and cement. Experience in New Jersey with unstabilized and bituminous stabilized open-graded drainage shows that both materials can be constructed without undue difficulty. The bituminous stabilized material offers a somewhat more stable working surface. Major problems in construction were segregation and contamination of the aggregate rather than placement or compaction of the drainage layer. Both types of material could support normal wheeled and tracked construction equipment. An asphalt laydown machine with small wheels rather than the more common tracks did bog down in the unstabilized drainage layer but also did the same in a nearby base course material. The asphalt stabilized material had to cool to lower temperatures (around 200° F) than normal asphaltic concrete (AC) to prevent rutting and shoving

under the roller. Porous concrete mixes have also been used for drainage and are summarized by Monahan (1981).

16. Contamination of the drainage layer must be prevented at all times. During construction stockpiles of drainage material must not become contaminated from blowing or washing fine material. Once the drainage layer is in place, wind blown and washed contaminants remain a potential problem. Traffic on the drainage layer must be kept to an absolute minimum to prevent fine material from entering and clogging the layer. Once in place, the drainage layer must be surfaced as soon as possible.

17. Once the drainage layer is functioning, water passing through the layer can carry material from surrounding area and clog the layer. This is aggravated by dynamic traffic loads. Positive filter protection must be provided to ensure that the drainage layer does not become clogged. Requirements for filter layers are provided in TM 5-820-2 (Headquarters, Department of the Army 1965). Filter fabrics have given mixed results. Performance history and criteria for their use are provided by the FHWA (1980b) and Miller (1979). New Jersey has gone to the extent of requiring a stabilized layer under the drainage layer.

18. Maintenance of outlets is a major requirement for a successful drainage system. Without it, outlets will clog and ruin the effectiveness of the system. The practice of "daylighting" a drainage layer appears questionable since blockage by fill, washed material, and vegetation seems likely.*

Drainage Application to Airfields

19. Most subsurface drainage has been oriented toward highway applications rather than airfields. Casagrande and Shannon (1952) described drainage problems at five airfields; four of these had subsurface drains, and one had a "daylighted" base. Cedergren (1974) describes a portion of a military heavy-duty airfield taxiway which has a 6-in.-thick AC surface over a 6-in. open-graded drainage layer. The field is not identified. Miller (1979) described the installation of a drainage system at Jacksonville airport. Other

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* Early experience has shown that lateral drains of "French-drain" construction using only relatively low permeability (less than 5 percent of minus 200 size) material leads to clogging and entrapment of water in the base.

open-graded drainage installations are at Kansas City and Portland airports. Only Casagrande and Shannon (1952) reported quantitative performance data.

20. Extending the highway experience to airfields raises several problems. Runways, taxiways, and aprons are much larger and will have longer drainage paths than highways. Since Darcy's law is of doubtful validity in analyzing flow in highly permeable open-graded drainage material, the calculation of design permeabilities, thicknesses, flow rates, etc. cannot be done with confidence. The problem is compounded for these long drainage paths where errors in the basic assumption of laminar flow may have a significant impact on design calculation.

21. Table A1 shows that if the assumptions of the FHWA (1980a) design recommendations are accepted for an approximation, an airfield pavement 150 ft wide could be kept drained for several design storms with a 6-in.-thick drainage layer with a permeability of 3,000 to 8,000 ft/day. If the base becomes saturated, Table A2 shows the length of time required to achieve several degrees of drainage for different permeabilities. The permeability of 0.28 ft/day (10^{-4} cm/sec) is equivalent to the heavily compacted base course aggregates tested by Nettles and Calhoun (1967). Tables A1 and A2 suggest, within the limitation of the calculation method, that permeabilities on the order of 1,000 to 10,000 ft/day would be appropriate for open-graded drainage layers for airfields. Figure A1 from the FHWA Manual (1980a) suggests that this limits consideration to uniform coarse sands and gravels. The Casagrande and Shannon test (1952) with a sandy gravel having an average permeability of 765 ft/day did not give results that agreed with the theoretical calculations based on laminar flow assumptions. The other Casagrande and Shannon test with sandy gravel was considered a suspect because of leakage in the test, but it also did not agree with theoretical calculations. These tests are of particular concern because there are only known tests which used drainage paths and slopes appropriate for an airfield.

22. Structural requirements are a greater problem for airfields than for highways due to the large aircraft loads. However, as previously discussed, there is little or no information available in this area. This is a question requiring further investigation and testing.

Table A1

Required Permeability of a 6-inch Drainage

Layer to Prevent Saturation

1 Hour/1 Year Frequency of Storm*	Infiltration Coefficient*	q**	Required k ft/day
2.0	0.50	1.00	5,900
	0.67	1.34	7,900
1.5	0.50	0.80	4,700
	0.67	1.00	5,900
1.0	0.50	0.50	2,900
	0.67	0.67	3,900

* Cedergren's method of estimating surface infiltration. Infiltration Coefficient of 0.33 to 0.50 for bituminous pavements, 0.50 to 0.67 for concrete pavements.
** q is design infiltration rate.

Drainage path length, 75 ft
Grade (maximum allowable transverse), 1.5%
Drainage layer maximum depth of flow, 6 in.

Figure 46 of FHWA Highway Subdrainage Design Manual is used to calculate k.

Table A2

Time Required for Drainage of a 6-inch-Thick Layer

Degree of Drainage (u)	t/m*	Time Required to Reach u			
		k = 0.28 ft/day	k = 100 ft/day	k = 1,000 ft/day	k = 10,000 ft/day
30%	0.066	53 days	14 hours	2.3 hours	25 minutes
50%	0.145	117 days	1.3 days	5.1 hours	54 minutes
90%	0.540	434 days	4.8 days	19.0 hours	3.4 hours

* f = time and $m = \dfrac{n'L^2}{K_d H_d}$

where: n' = yield capacity; L = Length; K_d = coefficient of permeability
H_d = thickness
Figure 47 of FHWA Highway Subdrainage Design Manual is used for calculating times.

Thickness of layer, 6 in.
Length of drainage path, 75 ft
Transverse slope, 1.5%

A7

Conclusions and Recommendations

23. The following conclusions were determined.

    a. There is sufficient potential benefit in airfield pavement drainage to warrant new Corps of Engineers research and testing.

    b. Existing Corps of Engineers subsurface drainage criteria (Headquarters, Department of the Army 1965) does not appear adequate in view of the results of Nettles and Calhoun (1967) tests and recent FHWA (1980a) work.

    c. There are a number of major questions about pavement drainage which can only be answered by further research and testing.

24. The following recommendations were made to conclude FY 81 study,

    a. Visit Professor Ridgeway to review his progress on the NCHRP Synthesis.

    b. Visit Jacksonville, Kansas City, and Portland airports to obtain as much detailed design, construction, and performance data as possible.

    c. Visit Michigan and California Department of Transportation to obtain available specifications, design, and performance data from their highway drainage projects.

25. Recommendations for future work were made as follows:

    a. Insufficient data are available on water inflow into pavements. Better methods of estimating inflow rates are necessary to develop design capacities for drainage layers.

    b. Major questions remain unanswered concerning the validity of our current methods of calculating flow in drainage layers with the assumption of laminar flow. This can only be answered with full scale experiments similar to those reported by Casagrande and Shannon (1952). These tests should include a conventional crushed stone base as a control and then other materials with permeabilities in the range contemplated for drainage layers (1,000 ft/day to 10,000 ft/day).

    c. There is not adequate experimental data available to allow an evaluation of the structural capacity of open-graded drainage layers for airfields. Basic performance data from laboratory and trafficking tests must be developed before analytical methods of selecting cover requirements can be developed.

    d. Open-graded drainage layers are in place at several airports. These should be instrumented and monitored by WES to obtain performance data if possible. Instrumentation should include areas without the drainage layers for comparison. Desirable data would include quantity of flow, in-place permeability, dynamic and static pore pressure, moisture contents, and nondestructive test structural evaluations.

A8

Current Research on Subdrainage and Related Topics

1. "Improving Subdrainage and Shoulders of Existing Pavements"

   Principal Investigators: Drs. Michael Darter and Barry Dempsey,
   University of Illinois

   Objectives: Establish criteria for the early identification of existing
   pavements in need of improved subdrainage and shoulders. Develop a method
   for determining optimum time to effect remedial measures. Establish
   guidelines for making improvements in subdrainage and shoulders. Pavement
   distress identification manual and procedures for identifying "Moisture
   Accelerated Distress" should be included in final report as well as
   shoulder design guides.

   Five reports to be published in 1981:

   a. "Structural Analysis and Design of PCC Shoulders"

   b. "Improving Subdrainage and Shoulder of Existing Pavements - State of
   the Art"

   c. "A Pavement Moisture Accelerated Distress Identification System Users
   Manual, Volume I"

   d. "A Pavement Moisture Accelerated Distress Identification System Users
   Manual, Volume II"

   e. "Improving Subdrainage and Shoulders of Existing Pavements, Final
   Report"

2. "Test Methods and Use Criteria for Filter Fabrics"

   Principal Investigators: Drs. J. R. Bell and R. G. Hicks, Oregon State
   University

   Objectives: Identify criteria for the engineering use of filter fabrics,
   particularly in subdrainage, erosion control, and soil reinforcement
   applications. Modify existing test methods and develop new test methods
   where needed to evaluate the engineering properties of filter fabrics.

   Final·Report - sometime in 1981

3. "Use of Filter Fabric as a Subgrade Retainer"

   Principal Investigator: Mr. Larry Smith, Florida Department of
   Transportation

   Objectives: Compare construction techniques and performance of three
   types of fabrics separating embankment material from underlying soft
   organic subsoil.

Completion Date - 1981 (Contract managed by FHWA Implementation Division - Mr. Chang).

4. "Engineering Fabrics Training Course"

   Principal Investigators: Haliburton and McGuffey

   Objectives: Develop course material and conduct workshops.

   Completion Date: 1981

NCHRP Contracts

1. Project 4-11 "Buried Plastic Pipe Drainage of Transportation Facilities"

   Contractor: Simpson, Gumpertz, and Heger, Cambridge, Massachusetts

   Principal Investigators: Richard Chambers, Frank J. Heger

   Objective: Develop and evaluate the design, installation, and performance criteria for the use of buried plastic pipe in transportation facilities.

   Final Report Published December 1980.

2. Synthesis Topic 11-07 "Pavement Drainage Systems" in NCHRP Project 20-5

   Principal Investigator: Dr. Hallas Ridgeway

   Objective: Establish the state of the art in design theory, and actual design and construction practices.

   Completion Date: 1981

HPR Studies

1. Alabama - "Design Parameters for Longitudinal Filter Cloth Lined Subsurface Pavement Drainage Systems"

   Principal Investigator: John Ball

   Objectives: Measure filter performance under controlled conditions, evaluate in field and propose specifications and test methods.

   Completion date: Draft Final Report received in December 1980

2. Alaska - "Applications of Engineering Fabrics in Alaska"

   Principal Investigator: Johnson

   Objective: Review performance of fabric installations and recommend guidelines for future use.

   Completion date: Unknown

A10

3. Alaska - "Roads on Muskeg"

   Principal Investigators: Johnson and Moses

   Objective: Reevaluate treatments to minimize settlement and distortion of roadways over peat deposits.

   Completion Date: September 1981

4. California - "Specification Expansion for Fabric Filters"

   Principal Investigator: Forsythe

   Objective: Establish standards of filtering capacity and permeability with appropriate test methods for nonwoven fabrics in civil engineering applications.

   Completion Date: June 1981

5. California - "The Effectiveness of Horizontal Drains"

   Principal Investigator: Duane Smith

   Objective: Develop effective cleaning system and maintenance and rehabilitation program.

   Completion Date: Draft report being revised.

6. Florida - "Permeability Characteristics of Base, Subbase, and Stabilized Subgrade Materials:

   Principal Investigator: K. H. Ho (Florida Department of Transportation)

   Objective: Measure permeability of typical construction materials.

   Completion Date: Unknown

7. Illinois - "Soil Water Properties of Subgrade Soils"

   Principal Investigators: Janssen and Dempsey

   Objectives: Determine the soil-water characteristics and saturated hydraulic conductivity of major soil types in Illinois.

   Completion Date: Final report published in 1980.

8. Kentucky - "Subsurface Drainage System for Highway Pavements"

   Principal Investigators: Newberry and Havens

   Objectives: Design, construct, and observe the performance of a pavement having a positive subsurface drainage system.

   Completion Date: 1981

9. Michigan - "Drainage and Foundation Studies for an Experimental Short Slab Pavement"

    Principal Investigators: M. Chiunti, T. M. Green, and E. C. Novak, Jr.

    Objective: Evaluate the comparative performance of jointed concrete pavement placed on conventional base, a porous bituminous drainage blanket and on a bituminous base.

    Completion Date: 1981? (Field test sections completed and under observation)

10. New Jersey - "Improved Drainage and Frost Action Criteria for New Jersey Pavement Design"

    Principal Investigator: George Koslov

    Objectives: Develop new pavement subdrainage criteria consistent with required strength and frost resistance.

    Completion Date: 1981?

11. Ohio - "Development and Implementation of Pavement Drainage Design Guidelines in Ohio"

    Principal Investigators: Elmitiny and Majidzadeh

    Objectives: Develop designs and construction specifications and guidelines for improved pavement subdrainage in new pavements.

    Completion Date: 1981

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Subsurface Drainage
1981

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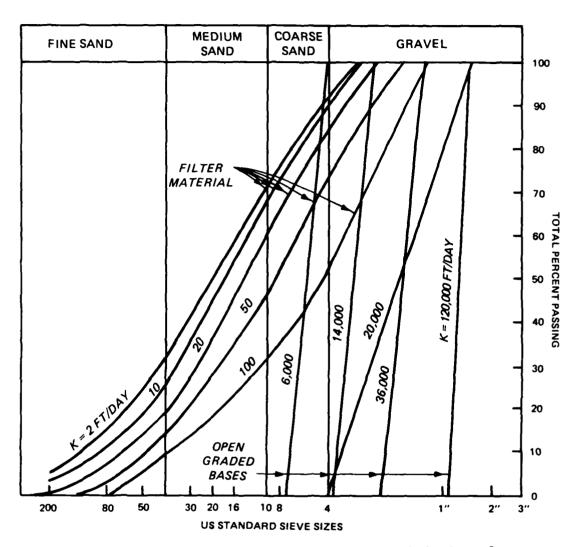
Figure Al. Typical gradations and permeabilities of
open-graded bases and filter materials
(From FHWA 1980a)

A14

APPENDIX B: MEMORANDUM FOR RECORD

MEMORANDUM FOR RECORD

SUBJECT: Subsurface Drainage, Jacksonville, FL

1. Person contacted:

>   Mr. Charles Hardrick
>   Director of Operations
>   Jacksonville Port Authority
>   PO Box 18097
>   International Airport
>   Jacksonville, FL 32229
>   Telephone No. 904-757-2265

2. Additional referenced obtained:

    a. Project drawings
    b. Project specifications
    c. "Comprehensive Study and Engineering Report for the Reconstruction of
the Terminal Apron and Taxiways at the Jacksonville International Airport"

3. Jacksonville Airport has a problem with a perched water table. Several
areas of the aprons show extensive staining from water seepage. Subgrade in
the airport area is variously a SC, SM, or SP with a blue-gray "Gumbo" clay
layer at shallow depths.

4. A keel section (50 by 7,000 ft) of runway was constructed in 1979. This
section consisted of a filter cloth on the subgrade, 6-in. open-graded
drainage layer, 6-in. econocrete layer, and a 16-in. PCC pavement. Trench
drains with pipes collect the overflow from the drainage layer and discharge
it into open drainage ditches. Two apron and parking areas have since been
reconstructed with drainage layers, and a fourth should begin construction by
the end of July.

5. Performance of drainage areas is considered satisfactory by the Port
Authority. This is based on visual appearance of water outflow of pipes and
lack of cracking or staining in new pavements with drainage layers.

6. Drainage layer aggregate used in one project section currently nearing
completion is a dusty limerock devoid of sand or fine aggregate sized
particles.

7. Inspectors report no particular problems with construction. The drainage layer is compacted with two passes of a vibratory roller (RayGo 400A on this project). All concrete is formed with saw cut joints in econocrete matching surface joints.

                                    RAYMOND S. ROLLINGS
                                    Engineer
                                    Pavement Systems Division
                                    Geotechnical Laboratory

WESGP   17 August 1981

MEMORANDUM FOR MR. A. H. JOSEPH, CHIEF, PAVEMENT SYSTEMS DIVISION*

SUBJECT: Report of Trip to Study Pavement Subdrainage Design, 6-24 July 1981

1. INTRODUCTION. This trip took me to three California DOT District Offices
and a like number of California highway projects under construction; two large
civilian airports, one in Portland, OR and the other in Kansas City, MO; the
Main Office of the Michigan DOT and their Research and Materials Laboratory as
well as two existing highways. One of the latter included 6 miles of experi-
mental pavement.

2. THREE DISTRICT OFFICES OF CALIFORNIA DOT.

    a. Monday through Wednesday, 6-8 July 1981; District No. 7 located in
Los Angeles. Individuals contacted at the District Office: Fred Correa,
Branch Chief of Engineering Services; William Lum, Hydraulics Engineer; Jim
Nakamura, Materials Engineer; Patricia Perovich, Project Development Engineer;
Dan Butler, Senior Engineer, Project Development Branch; Seige Watanabe, Mate-
rials Project Engineer. I obtained plans and specifications of their subpave-
ment drainage designs and visited two highway construction projects in the
district. Both projects included longitudinal drainage consisting of an
8-in.-diam perforated steel pipe (PSP) encased in cement-treated permeable
material (CTPM), running longitudinally beneath the shoulders. The roadway
pavement for both projects consists of a variable thickness PCC pavement slab.
The remainder of the pavement structures differed. The I-118 freeway
calls for a 0.40 ft lean concrete base directly under the pavement overlaying
a 0.40 ft aggregate base. A section of 300 ft includes a permeable drainage
blanket under the PCC slab. This area is reputed to have a wet subgrade. The
I-210 freeway designers chose to use a two-layer drainage system because of
the high ground-water level. The section as designed consisted of 0.65 ft of
CTPM over 0.25 ft of a Class 3 Asphalt Base. However, during construction the
0.65 ft CTPM was reduced in thickness to 0.45 ft. Over the CTPM, directly
beneath the concrete pavement, a 0.20 ft layer of AC was placed. The CTPM as
built is primarily against groundwater and not for protection against precipi-
tation. On both projects it was assumed that runoff would work its way
through the joints and cracks of the PCC pavement and that the lean concrete
base in the case of I-118 and the AC on the 210 freeway will act as aquifers

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* Appendix information describing supporting documents has been deleted from
   this memonrandum.

and lead the precipitation to the longitudinal drainage system outside the pavement edges.

b. Thursday, 9 July 1981, District No. 7 located in San Bernardino. I met with Mr. Tom Griffin, their Hydraulics Engineer, who offered nothing new that I had not already obtained from the Los Angeles District. However, I did visit a section of I-15 near Lake Elsinore. That highway is being retrofitted with a longitudinal drainage system along both shoulders. The design again consists of a filter fabric-lined trench with an 8-in. PSP encased in CTPM.

c. Friday, 10 July 1981, District No. 11 located in Sacramento. I met with Mr. Dale R. Schmodt, their District Hydraulics Engineer. Contrary to information that I received from the CA DOT Head Office in Sacramento, this district has not constructed nor is it in the process of building a section of highway pavement with the type of drainage design. However, the engineers are working on plans for highway designs that will incorporate the use of subpavement drainage systems. This they shared with me. I also spoke with two engineers from the CA DOT Transportation Laboratory in Sacramento. I was interested in the technical parameters for their treated permeable material. Mr. Raymond A. Forsythe, Chief of the Soil Mechanics and Pavement Branch, provided me with some basic information on ATPM as well as a copy of their laboratory report. In essence the ATPM consists of an open-graded aggregate between 3/4 in. and No. 4 aggregate bound with 2 percent AC which was found just enough to hold the particles together during construction. The placement temperature is between 250 and 300° F but may require cooling before it can be rolled. In the conclusion of this memorandum I will attempt to summarize some of the conclusions that I have seen in the field or read about in the literature. For the CTPM, I consulted with Mr. William Neal also from the CA DOT Laboratory. An interesting feature that I found in California's rigid pavement designs is that they do not provide for any dowels at their tranverse joints, tie bars at longitudinal joints, nor is any effort made to seal the joints.

3. PORTLAND, OR: MONDAY-WEDNESDAY, 13-15 JULY, 1981. I visited the Office of the Port of Portland on Monday. My point of contact was Mr. Jack Stiller, Project Manager for the Portland International Airport. Mr. Dick Lynch, a design engineer, took me out to see the airport paving. Two pavements were examined:

a. In 1974 a 2,200-ft extension on Runway 10R and parallel taxiway were constructed. The pavement was designed by Nai Yang based upon criteria that he developed while with the New York Port Authority. The structure of the pavements is somewhat unusual consisting of an AC surface course over a deep lime-cement-pozzolan-filler stabilized base. The specifications are included in Appendix B-02.650-1 and two drawings, Nos. P/A 74-3 1/58 and 18/58.

b. In 1979 2,500 ft of the north parallel taxiway were reconstructed, incorporating a 4-in. open-graded drainage blanket and an 8-in. perforated corrugated metal pipe. Mr. Lynch, the designer of the pavement, offered his comments on the "Questionnaire for Pavement Drainage Study."

c. While no studies have been conducted on any of the airport pavements, the Port of Portland indicated that they would be interested in participating in such a study with WES. The 1979 pavement was designed according to Cedergren's concepts and, therefore, may prove a good candidate for such an investigation.

4. KANSAS CITY, MO: WEDNESDAY AND THURSDAY, 15-16 JULY, 1981. I met with Mr. Bob Harrar of Burns and McDonnel, Consulting Engineers, who were involved in the design of the Kansas City International Airport (KCI) and Mr. Fred Berge, an engineer with the KCI. The section of pavement that was of primary interest was Taxiway C which is roughly 750 ft long by 75 ft wide. The pavement structure consists of 14 in. PCC pavement (reinforced), 6 in. AC base, and 6 in. untreated permeable material connected to longitudinal 6 in. PSP drains along the shoulders. The plans and specifications for this construction are attached along with an evaluation questionnaire that was completed by Mr. Harrar.

a. The problem with evaluating the performance of the pavement design is that no systematic investigation has been undertaken to gather any data. This holds true for the drainage blanket, the subdrainage system, and all other elements of the pavement structure. Occasionally and on an informal basis the condition of the pavements is inspected. The only criteria seem to be whether there is a visible pavement deterioration. The same holds true for the structural elements and for drainage features. The answers to the questionnaire that I left with Mr. Harrar further attest to this conclusion.

b. The airport pavements have been constructed over a period in excess of thirty years with numerous design techniques represented. The same holds true in some cases even for a single facility. Of all the locations that I visited, the owner which is the City of Kansas City Aviation Department seemed the most amenable to permitting WES to conduct studies of its pavement. I believe that Mr. C. Frederick Berge, the Airport Engineer, would prove most cooperative to such an undertaking.

c. My own visual observations of the pavements indicated that they seemed to be in good condition. From the scanty information that is available it appears evident that where open-graded drainage layers have been used, placing them beneath an impervious asphalt base does not permit them to drain water that has intruded into the pavement. Instead the precipitation flows beneath the PCC pavement slab and the asphalt base. The drainage blanket under the asphalt course may be carrying capillary moisture below the pavement structure.

5. LANSING, MI: FRIDAY-FRIDAY, 17-24 JULY, 1981. The agency that I visited
here was the Michigan DOT. The persons with whom I had contact and spent ap-
proximately a week of discussion and field investigation are as follows: Kent
Allemeier, Chief of Testing and Research; Don Mallot, Chief of Soils and Mate-
rials; Thomas A. Coleman, Supervising Engineer for Soils; Fred Copple, Head of
Research Services Unit; Carl Mainfort, Head of Soils Research; Edward Novak,
Supervisor for the Flexible Pavements Rheology Group; Shiou-San Kuo, Physical
Research Engineer; Leroy T. Dehler, Director of the Research Laboratory; and
Thomas Green and Manual Chiunti, Engineer Technicians.

    a. The significant results of the visit to the MI DOT headquarters were
the technical reports and other pertinent material obtained and the investiga-
tion of the experimental road section which is a 3 mile stretch of dual road-
way on US 10, northwest of Clare, MI. I expect to receive a set of slides
from the MI DOT on the construction of this test section. Unfortunately, the
roll of film that I took of the existing condition of the 12 test strips was
almost all overexposed. However, I made notes on each of the photographs
taken. The sections and typical cross-sections for each of the four types of
pavement are listed below. What is not shown is the retrofitted drainage
recently installed along the right shoulder at the Type D pavement strips. At
strip No. 1 the longitudinal drain was continuous, while at Nos. 3 and 9 it
was only installed at the transverse joints. The details of this drainage
installation are also listed. Essentially it is merely a pea gravel-filled
trench.

Section No.	Pavement Type	Comments
1	D	Faulting at most transverse joints between 1/4 in. to 1 in. Cores taken at joints indicated a loss of fines under the slab in direction of traffic.
2	A	Transverse cracking in the middle or third points of a number of slabs. No faulting of transverse joints evident.
3	D	Same as for Section No. 1.
4	B	Pavement appears in good condition.
5	C	Pavement appears in good condition. Cores were taken adjacent to the transverse joints to evaluate the condition of dowels. The plastic-coated ones were in the best condition followed by those coated with epoxy with the noncoated dowel bars most affected by corrosion.

Section No.	Pavement Type	Comments
6	A	Pavement appears in good condition. Transverse cracks in Section No. 2 are not evident.
7	C	Pavement appears in good condition.
8	A	Some slabs exhibit severe intermediate cracking with practically all slabs showing lesser degrees of it.
9	D	Considerable D-type cracking evident and much water standing along the transverse joints which indicates that pumping has taken place.
10	B	Pavement appears in good condition.
11	C	Pavement appears in good condition.
12	B	Pavement appears in good condition.

    b. Another slight modification was recently made to the pavement of this experimental strip. A joint was cleaned out between the PCC pavement and the AC shoulder. This space was filled with a sealant called "Sof-Seal Joint and Crack Sealing Compound." Based upon the feel of the material in the field, its memory that I was able to observe by manipulating it, the perfect condition that it appeared to be in, I consider it one of the most remarkable substances of its kind that I have ever come across. It is produced by W. R. Meadows, Inc., PO Box 543, Elgin, IL 60120. I have a long history of failures in joint sealants some of which are recorded in an article that I wrote for "Public Works" entitled "Search for Ideal Pavement Joint Sealants."

    c. This experimental section of US 10 is about five years old. Two of the four pavement types, A and D, show considerable distress. The two pavement types that appeared in all three sections in good condition, without visible stress, were B and C. Note the similarity of design between C and D except that Type C has dowel supports at the transverse joints. My overall impression is that Type B was the better design and is perhaps also the more economical one to construct.

6. DISCUSSION. It is difficult, if not impossible, to separate the subdrainage design from the overall consideration of the pavement structure. The general harmful influence of water upon a pavement structure is considered to be a major contributor to unsatisfactory performance and even failure. This situation manifests itself in rutting, cracking, faulting, increasing roughness, and a relatively rapid decrease in the level of the pavements serviceability. Trapped water in the pavement structure (surface, base, and subbase courses) and in the subgrade can result in pavement distress and ultimately to an unacceptable level of serviceability. Excess moisture from either precipitation

or groundwater adversely affects the ability of a pavement to sustain dynamic
loads imposed by traffic. In flexible pavements the damage is caused by the
temporary development of high pore water pressures in the aggregate courses of
the pavement structure and in the subgrade under the influence of dynamic
wheel loads. In the case of rigid pavements the mechanism is somewhat differ-
ent. The thermal regime results in a warping of the concrete slabs. A space
is created between the underside of the concrete slab and its subbase or sub-
grade which increases in size under the strains due to the traffic loads.
When free water is trapped beneath a slab joint, an approaching wheel load
causes the leading joint edge (in the direction of traffic) to deflect down-
ward as the trailing pavement slab edge rebounds upward. The result is a jet
of water and suspended fine soil particles opposite to the direction of traf-
fic which causes a faulting at the joint with the trailing edge moving upward
relative to the forward edge. If the transverse joints are not tightly sealed
a pumping action can be observed. This phenomenon can also be seen along the
outside edges of a pavement. While pumping and blowing are generally associ-
ated with rigid pavements, a somewhat similar process can also take place in
flexible pavements. There are a number of ways to deal with this problem, but
the most effective is to prevent free water from accumulating under pavement.
Other harmful effects of free water upon pavements are due to freezing and
thawing cycles and as a contributor to D-cracking of rigid pavements.

a. The faulting phenomenon was clearly evident in pavement Type D of the
experimental section of US 10 in Michigan. Except for Type B which had an
ATPM subbase, Types A and C which did not exhibit faulting have dowel
assemblies at the transverse joints. Interesting also that the only
D-cracking observed was in the Type D pavement. From what we know of
D-cracking, the presence of free water in pavement joints is a contributing
factor.

b. The method for determining the drainability of the various pavement
courses was first pioneered by Dr. Arthur Casagrande in 1951. At that time,
Professor Casagrande recommended that 10 days be allowed for drainage of the
various untreated aggregate layers in a pavement structure. Casagrande's
method of subbase drainage design utilized filter layers of well-graded mate-
rials possessing relatively low permeability, k , in the order of 100 ft/day
or less and an effective porosity n_e in the order of 0.1 or less.

c. The concept of drainage layers or blankets is predicted upon open-
graded aggregate materials with a permeability, k , of at least 10,000 ft/day
and an effective porosity in the order of 0.2. The design drainage time of
this layer is usually kept to a maximum of 1 hour. However, the design anal-
yses tools developed by Dr. Casagrande 30 years ago are still applicable.
Prior to the introduction of open-graded drainage layers, subsurface drainage
was generally used to remove ground water and water originating from artesian
sources but not for the rapid disposal of surface water that infiltrates into
the pavements structural section. The objective of these open-graded drainage
layers is to rapidly reduce the period of exposure of the entire pavement

structure to excess water. Even when sealed pavement surfaces conduct precip-
itation like sieves.

    d. These open-graded drainage layers are an integral part of the pavement
structure and should be placed immediately below the pavement surface. The
basic components of such a system include:

        (1) The open-graded highly permeable drainage layer. The discharge
capability is derived from Darcy's equation for laminar flow $Q/_i = kA$ where
Q = the flow in cu ft/day, i = hydraulic gradient in ft/ft, k = permeability
in ft/day, A = an area in sq ft. Therefore, the capacity of a drainage layer
is dependent upon permeability, thickness of the layer, and the hydraulic
gradient within the layer. The latter is determined by the pavement cross-
slope and the longitudinal grade.

        (2) Protection of the open-graded filter layer against clogging.
Protection must be provided during construction and for the life of the pave-
ment. Protection can be developed by the use of filter layers, filter fabric,
or by constructing the filter blanket on a fairly impervious foundation such
as an asphalt-treated base or a low-strength concrete base. All methods to
protect the filter layer envision it being constructed in a "sandwich" effect.

        (3) Collector trench and perforated pipe. These are generally drains
placed outside of and parallel to the pavement edges. The perforated pipe
should be between 3 and 8 in. in diameter, enveloped with a minimum of 6 in.
of carefully placed and properly graded filter aggregate which may be asphalt
or portland cement treated or untreated. It is often necessary to line the
trench with a filter fabric to protect the open-graded aggregate in the trench
from infiltration of fines.

        (4) Pipe outlets. Must be installed at locations and intervals dic-
tated by hydraulic design considerations to ensure a completely free-draining
system for the life of the pavement.

        (5) Markers. Should be installed at each collector pipe outlet to
assure visibility for maintenance purposes.

    e. At all four locations visited, California, Portland, OR, Kansas City,
MO, and Lansing, MI, limited sections of pavement have been constructed
incorporating elements of subdrainage blankets. At none of these locations
were any rigorous efforts made to develop analytical data on the performance
of these sections. The opinion of the engineers toward this approach to pave-
ment design is favorable. Attached are the results of a questionnaire that I
prepared before starting on this trip. The most significant project visited
was an experimental portion of freeway located on US 10 northwest of Clare, MI
While at Lansing, MI, I was shown a set of slides covering its construction

which is being furnished to me. I was most surprised with the pavements con-
structed or under construction in California. I-118, the Foothill Freeway now
under construction will have an 8-in. PSP longitudinal drain along the shoul-
ders encased in a cement-stabilized open-graded permeable material. The
inside of the longitudinal drainage trenches are to be lined with a filter
fabric. California designs all call for the permeable material to be stabi-
lized with about 2 percent AC or about 10 percent PCC. One recently completed
highway, 210 freeway in California, was designed with 0.65-ft CTPM directly
beneath a 0.70-ft PCC pavement. However, it was changed to a 0.45-ft CTPM
with 0.20 ft of AC between the drainage layer and the PCC pavement. The resi-
dent engineer, Ms. Marilyn Reece, informed me that this change was made in
order to permit accurate cores to be taken of the PCC pavement for thickness
determination as required by the contract specifications. It seemed to me
that the 0.20 ft of AC layer significantly nullified the objectives of the
CTPM layer. I discussed this matter with Mr. William Neal of the California
DOT Laboratory in Sacramento and he stated that he too questions the wisdom of
that 0.20 ft AC layer. He also made the observation that no provision for
instrumentation was made for any of the pavements and that only periodic
visual observations are planned. However, California does have plans to con-
struct pavements with full drainage layers in the near future. The typical
sections for I-105 in District No. 7 of the California DOT is in the final
design stage and construction is scheduled to begin within the next year.
Drawings and specifications are included herein. I find California's rigid
pavement designs particularly interesting and are somewhat different in con-
cept for the following reasons:

(1) All construction joints have a 1:6 skew, using a staggered length
of 12, 15, 13, and 14 ft. The panel lengths have recently been reduced from a
maximum of 19 ft.

(2) PCC pavement is constructed with no steel appurtenances of any
kind, not even tie bars at longitudinal joints. California apparently has
eliminated the use of all steel in its rigid pavements a number of years ago.
They depend upon friction to maintain the position of the longitudinal joints
and aggregate interlock for load transfer at transverse joints.

(3) California also stopped sealing joints some time ago as being
ineffective except when indicated as a maintenance operation.

7. CONCLUSIONS: It seems to me that the California DOT has come to the most
rational pavement design and one that I would like to see used in an airfield
test section utilizing a properly designed open-graded drainage layer together
with the other elements of such a pavement drainage system outlined in Sec-
tion 6, DISCUSSION. For a PCC I would recommend the elimination of all joint
fillers and sealants in construction joints. The incorporation of the open-
graded drainage layers, if properly designed, should result in a very rapid
removal of water from all pavement joints and cracks. Therefore, except dur-
ing times of precipitation the joints and cracks should be dry. Joint fillers

and joint sealants are expensive to install and maintain and at best they are
of limited effectiveness.   It seems to me that their elimination in all but
expansion joints would add a logical economic benefit to the use of open-
graded drainage blankets.   In my opinion this may prove to be a new and far-
reaching design concept for both rigid and flexible pavements that will
considerably extend the useful life of pavements and measurably reduce main-
tenance costs.   Such a test section might also include strips with and without
embedded steel components.   Instrumentation should be incorporated into the
pavement sections to determine the efficiency of both treated and untreated
permeable material both for drainage and as a structural component in the
pavement, effectiveness of measures to prevent clogging of the permeable mate-
rials, maximum time required to drain the pavement, correlating field against
laboratory permeabilities, etc.   At the present time the recommended design
permeabilities are one-third to one-half of the values obtained in laboratory
tests.

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APPENDIX C: ADDITIONAL REFERENCE MATERIAL

Completed Study References Anticipated by the Prior Survey (Appendix A)
and Other Pertinent References Available Since the Earlier Survey

NCHRP, Synthesis 96

1. A primary study anticipated by Ray Rollings initial survey was the NCHRP, Synthesis, "Pavement Subsurface Drainage Systems" by Professor Hallas H. Ridgeway which was completed in late 1982 and distributed in mid 1983. Primary context was design guidance which did not directly include performance information. Background similar to that of Appendix A is covered. Sources of water in pavements are listed. Permeability of new and old pavements and rate of water entry into cracks are discussed. The curves of Figure A1 are included. And information is included on permeability rates for six different aggregate gradations ranging from 10 to 3,000 ft/day.

2. Some current installations in various states were covered:

   a. **California.** A CALTRANS Memo urges designers to consider the need for longitudinal edge drains. A specification requires that permeable material for subdrains be asphalt or cement tested.

   b. **Pennsylvania.** PENDOT experience indicates that permeable bases can be used at competitive cost and provide adequate stability for construction when emplaced under RCC. These should have a minimum of material passing the #10 sieve. They find that 0.5 ft/day is too low and that 750 to 2,000 ft/day is satisfactory. PENDOT test sections are performing well after a year in place.

   c. **Michigan.** Michigan reports comparative installations of dense base and open base with the following findings:

Open Base	Dense Base
Permeability - 10 ft/day	Permeability - 300 ft/day
No outflow from edge drains	Large volume drain outflow
Assume no problem to construct	No problem to construct
No problem with behavior thus far	Performing well

   d. **Kentucky.** Kentucky has a 4-in. drainage blanket, test installation, under 6-in. black loase with 1-in. pavement and over 5-in. dense-graded base. The section has edge drains. Costs were competitive, and the design and construction involved no significant problems. This design has not been adopted as a standard, but is under further study.

C1

3. The Synthesis also includes summaries of several states and French experience with edge drains installed for rehabilitation of pavements.

4. General conclusions of Synthesis 96 and some observations are as follows:

a. Darcy's Law is adequate for design.

b. It is possible to drain only free water.

c. The primary source of free water is infiltration.

d. Permeability requirements for drainage layers are very high.

e. Effective filters are necessary for proper functioning of drainage systems.

f. The permeability of the subgrade material and location of the free-water surface must be known to permit proper design.

g. Wet soils or aggregates are not as strong as dry soils or aggregates, particularly when subject to repetitive loadings.

Observations

(1) State tests have covered drainage layers directly under pavements. These include graded aggregate, asphalt tested, and porous concrete materials. Construction has not been overly difficult, costs have been competitive with dense-graded aggregate bases, and to date installations are serving well.

(2) Edge drains in state tests have shown mixed results. Two conditions are notable: Edge support for the pavement must not be damaged, and material "feeding" water to the drain must be sufficiently permeable to pass the incident free water. It is also noted that cracks and joints must be sealed against infiltration.

(3) An overall determination is that infiltration and effects resulting from infiltration need to be of concern during the structure design process.

Other studies cited in Appendix A

5. The studies cited in Appendix A as ongoing and to be reported later have been examined through study of final reports or summarized information. Many of these address aspects of subdrainage do not direct contribute to this study. Pertinent comments are as follows:

a. FHWA administrative contacts. University of Illinois studies developed a Moisture Accelerates Distress MAD Index to indicate potential for moisture to contribute to pavement distress. The MAD Index directly uses the PCI for quantitative input on pavement condition. Other Illinois studies concerned PCC shoulders and improving subdrainage and shoulders of existing pavements. A "Final Report" includes conclusions that open-graded bases can improve performance, subgrade intrusion into open

bases must be prevented, and layer drainability must be considered. University of Oregon studies involve extensive examination of fabric types, fabric characteristics, and highway applications for filtration and other purposes. No base drainage or stability date are included. Florida DOT presents some comment on experience with fabric emplacement for subdrainage. No directly applicable base drainage or stability information is included.

b. NCHRP contacts. The Synthesis 96 report has been covered in depth earlier in this presentation. Project 4-11 on "Buried Plastic Pipe Drainage of Transportation Facilities" covers selection, design, and installation of plastic pipe for subsurface drainage. Directly applicable data on open-base drainage or stability are not included. Some applications to edge drains or cross-shoulder drains of base-layers may be applicable.

c. HPR studies. Alabama studies filter fabric applications to both French and pipe installed drains. Alaska studies concerned settlement analysis of peat in muskeg areas in relation to conventional settlement analyses. California reports experience with performance and maintenance of horizontal drains in hilly terrain. Florida studies are concerned with permeabilities of typical construction materials. Illinois reports studies of soil suction and soil-water relationships for Illinois soils. Kentucky has a test installation under observation comparing conventional dense-graded base with several patterns of open base under the surfacing and over a dense-graded layer. The dense base has no observable flow while the open bases show significant outflow. All sections are performing satisfactorily after about a year under traffic. Michigan has a test installation under observation and reports the asphalt treated porous base was easy to handle, extremely effective in removing infiltrated surface water, provides a stable platform on which to pave, and appears to be performing well. New Jersey studies have "served to identify an urgent need for better internal drainage solutions." Experimental subsurface drainage applications indicated that placement of bituminous stabilized open-graded base can be done using conventional equipment and some common sense without problems. Material should be cooled to 240° F to avoid "shoving." No problems were encountered with rutting on a layer beneath PCC, but severe rutting by the paver was experienced on an asphalt cement pavement job. Their conclusions are that 1,000 to 3,000 ft/day drainage is needed and construction problems or deficiencies can lead to rutting of either unstabilized or bituminous stabilized open bases. Ohio studied the permeability and laboratory stabilities of three asphalt stabilized materials and two porous concrete mixes. One porous concrete mix was impermeable and the other had 4,000 to 5,000 ft/day permeability. The bituminous stabilized gravel had about 2,200 ft/day permeability. Stabilized slag had 1,900 to 2,300 ft/day permeability. Stabilized limestone had permeabilities of 1,200 to 1,700 ft/day. Unstabilized limestone had 5,000 to 8,000 ft/day permeability. No field tests were

C3

involved, but computational analysis of "rutting" indicated no problems with the open materials.

Additional applicable references

6. A current search of the literature through the NTIS Database and some less formal searches have produced several references of note.

a. **Corps of Engineers open-base experience.** A study by T. Johnson of CRREL of Corps of Engineers, "Construction Experience with Granular Unbound Base Course with Very Low Fines Content" was reported in December 1986. Johnson reports experiences in British Columbia, Ontario, and five states of the US. Collectively these indicated strong interest in open-graded bases and demonstrate the conflict between good drainage and good stability. These agencies have accepted minimum and less than desired permeabilities to retain stability. They find that the stability of open-graded bases is marginal. By wing tracked equipment, excellent practice, and/or careful operations, they concluded that open bases can be constructed. They do report rolling problems and some wheeled vehicle problems. Johnson's reporting of Corps of Engineers experiences generally relates only to reduction of fines or -200 material. Reductions of the 0 to 10 percent used for dense grading to 0 to 2 percent or 0 to 3 percent has been successfully accomplished but not with complete freedom from stability problems. This type reduction largely fails to increase permeabilities to a desired range.

b. **A Pennsylvania paper.** A paper by Gary L. Hoffman in the 1982 "Transportation Research Record 849" entitled, "Subbase Permeability and Pavement Performance" concludes that (three orders of magnitude) higher permeability base can be constructed at competitive cost and with adequate stability to support construction equipment. The pavement was performing satisfactorily after a year's service.

c. **An Ontario paper.** A paper by MacMaster, Wrong, and Phang also in "TRR 849" entitled, "Pavement Drainage in Seasonal Frost Area, Ontario" concludes that performance use life can be appreciably curtailed by excess moisture. Open-graded drainage layers have had success in limited applications and will continue to be studied.

d. **Current periodical articles.** Civil Engineering magazine has an article entitled "Computer Assisted Pavement" in the September 1986 issue, which advocates an alternate pavement section involving a drainage layer. The March 1987 issue of Civil Engineering has a CALTRANS article entitled, "The Road to Drained Pavements" which describes California's commitment to improved pavement drainage. The "Forum" at the front of the April 1987 issue of Civil Engineering is an item by Cedergren indicating "Undrained Pavements: A Costly Blunder." The March 1987 issue of "Roads and Bridges" magazine includes an article on "Geomembranes Defeat Moisture in Pavements" presenting information on some Texas test installations.

References

7. A list of references pertinent to this appendix is presented here:

a. NCHRP Synthesis of Highway Practice 96, "Pavement Subsurface Drainage Systems," November 1982, by Hallas H. Ridgeway.

b. FHWA/RD-81/122, "Structural Analysis and Design of PCC Shoulders," by the University of Illinois, April 1982, Final Report.

c. FHWA/RD-81/077, "Improving Subdrainage and Shoulders of Existing Pavements," by the University of Illinois, August 1982, "State of the Art."

d. FHWA/RD-81/079, "A Pavement Moisture Accelerated Distress (MAD) Identification System" by the University of Illinois, September 1981, Volumes I and II, Final Report.

e. FHWA/RD-80/021, "Evaluation of Test Methods and Use Criteria for Geotechnical Fabrics in Highway Applications," June 1980, by Oregon State University.

f. FHWA/RD-81/078, "Improving Subdrainage and Shoulders of Existing Pavements," by the University of Illinois, January 1982, "Final Report."

g. FHWA/FL/BMR-85-295, "The Use of Filter Fabric As a Subgrade Retainer," November 1985, by Florida DOT.

h. NCHRP Report 225, "Plastic Pipe for Subsurface Drainage of Transportation Facilities," Project 4-11, October 1980, by Chambers, McGrath, and Heger.

i. HPR No. 91, The Alabama Highway Dept., "Design Parameters for Longitudinal Geotextile Line Subsurface Pavement Drainage Systems," by Ball, Miller, Scofield, and McMinn.

j. FHWA-AK-RD-83-1, "Evaluation of Road Construction by Surcharge Over Muskeg," by Eric G. Johnson, Alaska DOT.

k. FHWA/CA/TL-81/11, "Nonwoven Geotextile Fabrics: Evaluation and Specification for Subdrainage Filtration," by T. P. Hoover of CALTRANS, May 1981.

l. FHWA/CA/TL-80/16, "The Effectiveness of Horizontal Drains," by Duane D. Smith of CALTRANS, June 1980.

m. FHWA/IL/UI-184, "Soil Water Properties of Subgrade Soils," by Janssen and Dempsey, University of Illinois, Project IHR-606, April 1980.

n. UKJRP-83-13, "Water Under Pavements," by Havens and Sharpe, Kentucky DOT, July 1983.

o. FHWA/NJ-84/012, "Improved Drainage and Frost Action Criteria for New Jersey Pavement Design" by George S. Kozlov, New Jersey DOT.
Volume I, "Investigations for Subsurface Drainage."
Volume II, "Experimental Subsurface Drainage Applications."

Volume III, "Road Subsurface Drainage Design, Construction and Maintenance Guide for Pavements."

p. FHWA/NJ-84/015, "Improved Drainage and Frost Action Criteria for New Jersey Pavement Design, Volume III, Road Subsurface Drainage Design, Construction and Maintenance Guide for Pavements," by George S. Kozlov, N.H. DOT, March 1984, Final Report.

q. FHWA/OH-81/007, "Development and Implementation of Pavement Drainage Design Guidelines in Ohio," by Majidzadeh and Elmitiny, Ohio DOT, March 1981.

r. US Army Engineer, CRREL report, "Construction Experience with Granular Unbound Base Course with Very Low Fines Content," by T. Johnson, December 1986.

s. TRR 849, "Symposium on Aspects of Subsurface Drainage Related to Pavement Design and Performance," 1982.
Paper: "Subbase Permeability and Pavement Performance," by Gary L. Hoffman
Paper: "Pavement Drainage in Seasonal Frost Area, Ontario," by MacMaster, Wrong, and Phang.

t. Civil Engineering magazine for September 1986, "Computer Assisted Pavement," by Miller, Ridhter, and Durkis.

u. Civil Engineering magazine for April 1987, "Undrained Pavements: A Costly Blunder," by Harry R. Cedergren.

v. Roads and Bridges magazine for March 1987, "Geomembranes Defeat Moisture in Pavements," by Alyce Vacha.

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